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(54) Recombinant bovine herpesvirus type 1 polyptpetides and vaccines

(57) Recombinant subunit vaccines against bovine herpesvirus type 1 (BHV-1) are provided, as well as methods of vaccination and methods of recombinantly producing the subunit antigens or nucleotide sequences employed in the vaccines. Preferably, the subunit is a truncated BHV-1 gIV antigen.

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Description

Technical Field

The present invention relates generally to the prevention of disease in cattle. More particularly, the instant invention is directed to the recombinant production of certain bovine herpesvirus type 1 (BHV-1) antigens especially a truncated BHV-1 gIV antigen, for use in vaccines to protect cattle against bovine herpesvirus type 1 infection.

Bovine herpesvirus type 1 (BHV-1) is an economically significant pathogen of cattle. BHV-1, which is also known as infectious bovine rhinotracheitis virus, causes severe respiratory infections, conjunctivitis, vulvovaginitis, abortions, encephalitis, and generalized systemic infections. If an animal recovers from a primary infection, the virus remains in the host in a latent state. Reactivation of the virus can be provoked by certain endogenous or exogenous physical modifications in the animal, or experimentally by treatment of the animal with glucocorticoids like dexamethasone.

In an effort to control BHV-1 infections, killed virus and attenuated live-virus vaccines have been developed. While these vaccines appear to induce some level of protection in cattle, the level of immunity is well below that necessary to afford complete off near-complete protection. For example, the vaccines do not always prevent the establishment of a latent infection by a virulent field strain of BHV-1. Furthermore, the safety of the live-virus vaccines has been questioned. It has been shown recently that two live BHV-1 vaccine strains can be reactivated by the use of dexamethasone, indicating that at least some BHV-1 vaccines can themselves establish a latent infection. See, e.g., Gerber et al. (1978) Am. J. Vet. Res. 39:753-760; Jericho et al. (1983) Can. J. Com. Med. 47:133-139; Pastoret et al. (1980) Infect. Immun. 29:483-488. Subunit vaccines, i.e. vaccines including select proteins separated from the whole virus, afford a method for overcoming the problems inherent in the use of live and attenuated virus vaccines.

Several polypeptides of BHV-1 have now been studied. Misra et al. (1981) J. Virol. 40:367-378, reports on the partial characterization of a number of BHV-1 polypeptides and their immunoprecipitation with antiserum. van Drunen Littel-van den Hurk et al. (1984) Virology 135:466-479 and van Drunen Littel-van den Hurk et al. (1985) Virology 144:216-227 are directed to monoclonal antibodies developed against BHV-1 glycoproteins, and the ability of the monoclonal antibodies to neutralize virus and participate in antibody-dependent complement-mediated lysis in vitro. See also Collins et al. (1984) J. Virol. 52:403-409; Okazaki et al. (1986) Virology 150:260-264. van Drunen Littel-van den Hurk et al. (1985) Virology 144:204-215 is directed to the purification of BHV-1 glycoproteins by immunoadsorbent chromatography and the production of antiserum in rabbits. van Drunen Littel-van den Hurk et al. (1986) J. Clin. Microbiol. 23:274-282 is directed to in vitro immunoreactivity of purified BHV-1 glycoproteins and bovine antiserum. Okazaki et al. (1987) Arch. Virol. 92:17-26 pertains to in vitro studies of the reactivities of monoclonal antibodies against BHV-1 glycoproteins with infected cells. Babiuk et al. (1987) Virology 159:57-66 relates to the purification of gI, gIII and gIV from virus infected cell lysates. This reference also discloses that gI of BHV-1 corresponds to gB of herpes simplex virus (HSV); gIII corresponds to gC; and gIV corresponds to gD. Purified gI, gIII and gIV have been shown to induce high levels of neutralizing antibody in cattle and participate in antibody dependent cell cytotoxicity of BHV-1 cells. The purified glycoproteins were also shown to protect cattle from disease. Babiuk et al. (1987) Virology 159:57-66. van Drunen Littel-van den Hurk et al. (1990) Vaccine 8:358-368 confirmed the protectivity of gI, gIII and gIV and studied the epitope specificity of the immune response to the glycoprotein vaccines. Hughes et al. (1988) Arch. Virol. 103:47-60 identified three neutralizing antigenic domains on gIV.

Mayfield et al. (1983) J. Virol. 47:259-264 discloses the cloning of a BHV-1 strain and a restriction map. Fitzpatrick et al. (1989) Virology 173:46-57, describe the nucleotide sequence of gIII. Pachl et al. (1987) J. Virol. 61:315-325 describe the recombinant expression of a glycoprotein from the human pathogen HSV-1. There was no demonstration, however, that the recombinant polypeptide from the human virus was, in fact, protective in a human host. See also PCT Pub. No. WO88/02634; U.S. Patent Nos. 4,661,349; 4,642,333.

Fitzpatrick et al. (1988) J. Virol. 62:4239-4248 describe the expression of gI and gIII in murine LMTK-cells. The transfected cells were shown to stimulate the production of neutralizing antibodies in mice. Fitzpatrick et al. (1990) describe the expression of deleted, truncated and hybrid farms of gI and gIII in murine LMTK-cells and epitope mapping of the same. Tikoo et al. (1990) J. Virol. 64:5132-5142 disclose the mapping, cloning and sequencing of BHV-1 gIV, as well as the expression of gIV in bovine cells. van Drunen Littel-van den Hurk et al. (1989) J. Virol. 63:2159-2168 disclose the expression of gI and gIII in a vaccinia virus vector. The recombinant vectors elicited a neutralizing antibody r sponse in cattle immunized with the same. van Drunen Littel-van den Hurk et al. (Jan. 1991) J. Virol. 65: 263-271 describe the expression of gIV by recombinant baculovirus. This disclosure was based in part on the present invention. Cattle immunized with recombinant gIV raised neutralizing antibodies thereto.

U.S. patent 5,151,267 issued September 29, 1992 discloses vaccines comprising at least one recombinant antigenic determinant of BHV-1 gI, BHV1-gIII and/or BHV-1 gIV and the preparation thereof. Babiuk et al. Virology 159:57-66 (1987) also describes the protection of cattle with individual viral BHV-1 glycoproteins.

Disclosure of the Invention

It has been discovered that recombinant subunit vaccines, based on selected BHV-1 glycoproteins, will protect cattle from disease. These vaccines are particularly useful in protecting cattle from the shipping fever complex syndrome which often includes infection by BHV-1. Surprising, these subunit vaccines are substantially more protective than prior art killed virus and attenuated live-virus vaccines. The recombinant subunit vaccines do not suppress the immunological response to other components often found in multivalent attenuated shipping fever viral vaccines. Further, the recombinant subunit vaccines of the present invention also eliminate the risk of infection from the live-virus vaccines. It has also been discovered that recombinant BHV-1 polypeptides maintain the proper epitopes necessary to protect immunized animals from disease. Both nonglycosylated polypeptides, and polypeptides glycosylated by heterologous host organisms, effectively elicit antibodies that neutralize virus infectivity and induce complement-mediated cell lysis. Based on these discoveries, the present invention can take several embodiments.

The present invention is directed to a vaccine composition comprising a pharmaceutically acceptable vehicle plus a recombinant subunit antigen comprising a truncated bovine herpesvirus type 1 (BHV-1) gIV glycoprotein, optionally with at least one additional recombinant subunit antigen comprising a neutralizing epitope of glycoprotein selected from the group consisting of BHV-1 gI, BHV-1 gIII and a second BHV-1 gIV protein. Production of a truncated protein was by secretion. An example of a plasmid containing a truncated BHV-1 gIV is pG4HUNEO having the ATCC accession number 69076.

In other embodiments, the subject invention is directed to nucleotide sequences encoding proteins substantially homologous and functionally equivalent to truncated BHV-1 gIV.

In yet other embodiments the subject invention is directed to DNA constructs comprising an expression cassette comprised of: (a) a DNA coding sequence for a polypeptide containing at least one neutralizing epitope of a truncated BHV-1 gIV; and (b) control sequences that are operably linked to the coding sequence whereby the coding sequence con be transcribed and translated in a host cell, and at least one of the control sequences is heterologous to the coding sequence.

In another embodiment, the present invention is directed to a host cell stably transformed by the above DNA constructs.

In still another embodiment, the subject invention is directed to methods of producing recombinant truncated BHV-1 gIV polypeptides comprising:

(a) providing a population or the above host cells; and
(b) growing the population of cells in a growth media under conditions whereby the polypeptide encoded by the expression cassette is expressed and secreted; and optionally
(c) recovering the secreted truncated BHV-1 gIV polypeptide from the growth media.

In another embodiment, the instant invention is directed to methods of treating or preventing BHV-1 infection in a bovine host comprising administering to the bovine host a therapeutically effective amount of a vaccine compositions described above.

These and other embodiments of the present invention will readily be apparent to those of skill in the art from the following disclosure.

Brief Description of the Figures

Figure 1 is the nucleotide sequence and deduced amino acid sequence from a viral clone of gIV. The gene encodes a peptide 417 amino acids long. The right-angle arrow marks the position of the mature gIV sequence. Putative transmembrane sequences are underlined.

Figure 2 shows the construction of the vaccinia expression vector pVV-1.

Figure 3 depicts the construction of the vaccinia expression vector pVVSL-1.

Figure 4 depicts the vaccinia expression vector pVV-1/gIV with the full length gIV gene cloned into the BglII cloning site of pVVSL-1.

Figure 5 shows the vaccinia expression vector pVV-1/gIVt which includes a modified BHV-1 gIV gene inserted into the BglII cloning site of pVVSL-1.

Figure 6 shows various BHV-1 genomic library clones.

Figure 7 depicts the E. coli expression plasmid pgp11 complete, carrying the entire glb coding sequence plus DNA encoding the first eight amino acids of glc. See Example V.

Figure 8 shows the E. coli expression plasmid pBHC150Δ, carrying a deletion mutant of the BHV-1 gIII gene. See Example V.

Figure 9 shows the cloning strategy and the construction of pBHDsib. See Example V.

Figure 10 depicts the E. coli expression plasmid pBHDsib, containing a gIV gene encoding the mature protein. See Example V.

Figure 11 depicts the adenovirus transfer vector, pAdBM5. * indicates the gene insertion site. See Example VI.

Figure 12 shows the adenovirus vector, pAdBM5.gIV, which includes the gene coding for full-length gIV. See Example VI.

Figure 13 shows the effects of immunization with truncated BHV-1 gIVA protein (-▲-), as compared to gIVA (-■-) and a placebo (-o-) in virus shedding in animals challenged with BHV-1.

Figure 14 shows the daily number of sick calves when treated with BHV-IV protein, truncated BHV-IV protein and a placebo.

Figure 15. Structure of BHV-1 gIV deletions and truncations. The amino acid sequence of gIV is depicted schematically, at the top of the figure, with signal sequence

( ),

, transmembrane anchor sequence

( ),

, cysteine residues (S) and potential N-linked glycosylation sites (†). Deleted or truncated forms of gIV are shown below the diagram of intact gIV with the deleted regions indicated by solid line

( )

. The name given to each mutant protein is indicated on the right.

Figure 16. Predicted secondary structure of BHV-1 gIV. The deduced amino acid sequence of gIV was analyzed for alpha-helix, beta sheet, and beta turn probabilities using a version of algorithm of Chou and Fasman. Segments of alpha-helix, are looped, segments of beta sheets are zig-zagged, and beta turns are indicated as bends. Cysteine residues (C) and potential N-linked glycosylation sites (N) are indicated. The approximate location of the mapped epitope: is indicated by arrows whereas the region of the gIV required for proper processing and transport marked by bracket.

Figures 17(a) and (b) show the effects of immunization with truncated BHV-1 gIV vaccine.

Detailed Description

The practice of the present invention will employ, unless otherwise indicated, conventional virology, microbiology, molecular biology and recombinant DNA techniques within the skill of the art. Such techniques are explained fully in the literature. See, e.g., Sambrook, et al., Molecular Cloning: A Laboratory Manual (2nd Edition, 1989); Maniatis et al., Molecular Cloning: A Laboratory Manual (1982); DNA Cloning: A Practical Approach, vol. I & II (D. Glover, ed.); Oligonucleotide Synthesis (N. Gait, ed., 1984); Nucleic Acid Hybridization (B. Hames & S. Higgins, eds., 1985); Transcription and Translation (B. Hames & S. Higgins, eds., 1984); Animal Cell Culture (R. Freshney, ed., 1986); Perbal, A Practical Guide to Molecular Cloning (1984).

All patents, patent applications and publications cited herein, whether supra or infra, are hereby incorporated by reference in their entirety.

A. Definitions

The following terminology will be used in accordance with the definitions set out below in describing the present invention.

A DNA "coding sequence" is a DNA sequence which is transcribed and translated into a polypeptide in vivo when placed under the control of appropriate regulatory sequences. The boundaries of the coding sequence are determined by a start codon at the 5' (amino) terminus and a translation stop codon at the 3' (carboxy) terminus. A coding sequence can include, but is not limited to, procaryotic sequences, cDNA from eucaryotic mRNA, genomic DNA sequences from eucaryotic (e.g., mammalian) DNA, and even synthetic DNA sequence. A polyadenylation signal and transcription termination sequence will usually be located 3' to the coding sequence.

A "promoter sequence" is a DNA regulatory region capable of binding RNA polymerase in a cell and initiating transcription of a downstream (3' direction) coding sequence. For purposes of defining the present invention, the promoter sequence is bound at the 3' terminus by the translation start codon (ATG) of a coding sequence and extends upstream (5' direction) to include the minimum number of bases or elements necessary to initiate transcription at levels detectable above background. Within the promoter sequence will be found a transcription initiation site (conveniently defined by mapping with nuclease S1), as well as protein binding domains (consensus sequences) responsible for the binding of RNA polymerase. Eucaryotic promoters will often, but now always, contain "TATA" boxes and "CAT" boxes. Procaryotic promoters contain Shine-Dalgarno sequences in addition to the -10 and -35 consensus sequences.

DNA "control sequences" refers collectively to promoter sequences, ribosome binding sites, polyadenylation signals, transcription termination sequences, upstream regulatory domains, enhancers, and the like, which collectively provide for the transcription and translation of a coding sequence in a host cell.

A coding sequence is "operably linked to" or "under the control of" control sequences in a cell when RNA polymerase will bind the promoter sequence and transcribe the coding sequence into mRNA, which is then translated into the polypeptide encoded by the coding sequence.

A "host cell" is a cell which has been transformed, or is capable of transformation, by an exogenous DNA sequence.

A cell has been "transformed" by exogenous DNA when such exogenous DNA has been introduced inside the cell membrane. Exogenous DNA may or may not be integrated (covalently linked) to chromosomal DNA making up the genome of the cell. In procaryotes and yeasts, for example, the exogenous DNA may be maintained on episomal element, such as a plasmid. With respect to eucaryotic cells, a stably transformed cell is one in which the exogenous DNA has become integrated into the chromosome so that it is inherited by daughter cells through chromosome replication. This stability is demonstrated by the ability of the eucaryotic cell to establish cell lines or clones comprised of a population of daughter cells containing the exogenous DNA. Episomal replication is also possible in mammalian cells e.g. plasmids containing the EBV ori and EBNA gene, SV40 plasmids in COS cells.

A "clone" is a population of cells derived from a single cell or common ancestor by mitosis. A "cell line" is a clone of a primary cell that is capable of stable growth in vitro for many generations.

Two DNA or polypeptide sequences are "substantially homologous" when at least about 85% (preferably at least about 90%, and most preferably at least about 95%) of the nucleotides or amino acids match over a defined length of the molecule. DNA sequences that are substantially homologous can be identified in a southern hybridization experiment under, for example, stringent conditions, as defined for that particular system. Defining appropriate hybridization conditions is within the skill of the art. See, e.g., Maniatis et al., supra; DNA Cloning, vols I & II, supra; Nucleic Acid Hybridization, supra.

The term "functionally equivalent" intends that the amino acid sequence of the subject protein is one that will elicit an immunological response, as defined below, equivalent to the specified BHV-1 immunogenic polypeptide.

A "heterologous" region of a DNA construct is an identifiable segment of DNA within or attached to another DNA molecule that is not found in association with the other molecule in nature. Thus, when the heterologous region encodes a viral gene, the gene will usually be flanked by DNA that does not flank the viral gene in the genome of the source virus or virus-infected cells. Another example of the heterologous coding sequence is a construct where the coding sequence itself is not found in nature (e.g., synthetic sequences having codons different from the native gene). Allelic variation or naturally occurring mutational events do not give rise to a heterologous region of DNA, as used herein.

A composition containing molecule A is "substantially free of" molecule B when at least about 75% by weight of the total of A + B in the composition is molecule A. Preferably, molecule A comprises at least about 90% by weight of the total of A + B in the composition, more preferably at least about 99% by weight.

"Bovine host" refers to cattle of any breed for which it may be desirable to immunize against BHV-1 infection, whether or not the bovine host is already infected or latently infected by BHV-1. A bovine host can be of any age. Thus, the term encompasses calves as well as adult cattle.

"Native" proteins or polypeptides refer to proteins or polypeptides recovered from BHV-1 virus or BHV-1 infected cells. Thus, the term "native BHV-1 polypeptide" would include naturally occurring BHV-1 proteins and fragments thereof. "Non-native" polypeptides refer to polypeptides that have been produced by recombinant DNA methods or by direct synthesis. "Recombinant" polypeptides refer to polypeptides produced by recombinant DNA techniques; i.e., produced from cells transformed by an exogenous DNA construct encoding the desired polypeptide.

An "antigen" refers to a molecule containing one or more epitopes that will stimulate a host's immune system to make a humoral and/or cellular antigen-specific response. The term is also used interchangeably with "immunogen."

By "subunit antigen" is meant an antigen entity separate and discrete from a whole virus (live or killed). Thus, an antigen contained in a cell free extract would constitute a "subunit antigen" as would a substantially purified antigen.

A "hapten" is a molecule containing one or more epitopes that does not stimulate a host's immune system to make a humoral or cellular response unless linked to a carrier.

The term "epitope" refers to the site on an antigen or hapten to which a specific antibody molecule binds. The term is also used interchangeably with "antigenic determinant" or "antigenic determinant site."

An "immunological response" to a composition or vaccine is the development in the host of a cellular and/or antibody-mediated immune responses to the composition or vaccine of interest. Usually, such a response consists of the subject producing antibodies, B cells, helper T cells, suppressor T cells, and/or cytotoxic T cells directed specifically to an antigen or antigens included in the composition or vaccine of interest.

The terms "immunogenic polypeptide" and "immunogenic amino acid sequence" refer to a polypeptide or amino acid sequence, respectively, which elicit antibodies that neutralize viral infectivity, and/or mediate antibody-complement or antibody dependent cell cytotoxicity to provide protection of an immunized host. An "immunogenic polypeptide" as used herein, includes the full length (or near full length) sequence of the desired BHV-1 glycoprotein or an immunogenic fragment thereof. By "immunogenic fragment" is meant a fragment of a polypeptide which includes one or more epitopes and thus elicits antibodies that neutralize viral infectivity, and/or mediates antibody-complement or antibody dependent cell cytotoxicity to provide protection off an immunized host. Such fragments will usually be at least about 5 amino acids in length, and preferably at least about 10 to 15 amino acids in length. There is no critical upper limit to the length of the fragment, which could comprise nearly the full length of the protein sequence, or even a fusion protein comprising fragments of two or more of the BHV-1 subunit antigens.

The term "treatment" as used herein refers to either (i) the prevention of infection or reinfection (prophylaxis), or (ii) the reduction or elimination of symptoms of BHV-1 (therapy).

B. General Methods

Bovine herpesvirus type 1, or BHV-1, is a well-known and well-characterized virus, of which many strains are known. See, e.g., Gibbs et al. (1977) Vet. Bull. (London) 47:317-343. BHV-1, also known as infectious bovine rhinotracheitis virus, is similar in structure to other herpesviruses, and possesses a linear double-stranded DNA genome of approximately 140 kilobase pairs. BHV-1 can remain latent in infected animals, probably in trigeminal or sacral ganglia, and, as discussed above, can be reactivated with relative ease.

The antigen of the present invention is a truncated BHV-1 gIV and optionally used with at least one additional subunit antigen comprising a antigenic determinant selected from the group of BHV-1 glycoproteins consisting of gI, gIII, and a second gIV. These optional antigens are disclosed in U.S. patent 5,151,267 issued September 29, 1992.

The truncated gIV sequence need only encode a "polypeptide neutralizing epitope"; i.e., an epitope which elicits antibodies that neutralize virus infectivity, and/or mediates antibody-complement or antibody dependent cell cytotoxicity to provide protection of an immunized host. See, e.g., Babiuk et al. (1975) Infect. Immun. 12:958-963; Babiuk et al. (1987), supra.

In general, the polypeptide subunit antigens will usually be at least about 5 amino acids in length in order to encode an epitope, and preferably at least about 10-15 amino acids in length. There is no critical upper limit to the length of the subunit antigen, which could comprise the entire viral glycoprotein sequence, or even a fusion protein comprising the sequences of two or more of the viral glycoproteins.

The truncated and optional antigens of the present invention are recombinant polypeptides. These recombinant antigens can take the form of partial glycoprotein sequences, full-length viral protein sequences, or even fusion proteins (e.g., with an appropriate leader for the recombinant host, or with another subunit antigen sequence for BHV-1 or another pathogen). The antigen, even though carrying epitopes derived from glycoproteins, does not require glycosylation. The generation of truncated BHV-1 gIV gene constructs was for directing secretion of gIV for the purposes of 1) increasing gIV yields and 2) producing gIV in relatively pure form by simply harvesting from the growth media.

Particularly preferred epitopes for screening the antigens will be those epitopes that are exposed on the cell membrane of infected host cells, as well as those epitopes encompassing the attachment site on intact virions. Such epitopes can be defined by monoclonal antibody analysis. See, e.g., van Drunen Littel-van den Hurk et al. (1985) Virology 144:216-227; Okazaki et al. (1987), supra.

In the vaccines of the present invention, it will sometimes be preferable to have more than one polypeptide neutralizing epitope in the antigen(s). Furthermore, it nay also be desirable to include polypeptide neutralizing epitopes from more than one glycoprotein in the antigen(s). In its simplest form, this can be achieved by employing a polypeptide encoding a truncated BHV-1 gIV alone or optionally with the partial or complete sequence of a glycoprotein (usually encompassing more than one neutralizing epitope), or by employing a combination of polypeptides encoding the sequences of two or three of the viral glycoproteins (e.g. gI, gIII and gIV).

The antigens of the present invention, may be conjugated to a vaccine carrier. Such carriers are well known in the art, such as bovine serum albumin (BSA), human serum albumin (HSA) and keyhole limpet hemocyanin (KLH). A particularly preferred carrier protein, rotavirus VP6, is disclosed in U.S. patent No. 5,071,651, the disclosure of which is hereby incorporated by reference in its entirety. The BHV-1 neutralizing epitopes of the present invention may also be incorporated within particle-forming viral polypeptides as a fusion protein, as described in U.S. Patent No. 4,722,840 and EPO Pub. No. 174,759. Alternatively, the BHV-1 antigens of the present invention can be incorporated into a foreign virus (e.g. vaccinia or adenovirus) as is known in the art and described more fully below in the examples.

The antigen(s) are formulated into a vaccine composition comprising a pharmaceutically acceptable vehicle and, optionally, an adjuvant. Such formulations are well within the skill of the art. In general, the formulations will be particularly adapted for intra-muscular injection, since intravenous injection is usually not practical for large-scale application to domestic animals. Alternatively, the vaccines are given orally or intranasally, and the subunits formulated with a suitable oral carrier. It may be preferred to administer the vaccines of the present invention orally to raise mucosal immunity, as well as intramuscularly for systemic immunity. A pharmaceutically acceptable vehicle, suitable for parenteral injection, is usually nontoxic and nontherapeutic. Examples of such vehicles arc water, saline, Ringer's solution, dextrose solution, and Hank's solution. Nonaqueous vehicles, such as fixed oils, sesame oil, ethyl oleate, or triglycerides may also be used. Parenteral vehicles may also take the form of suspensions containing viscosity enhancing agents, such as sodium carboxymethylcellulose, sorbitol, or dextran. The vehicle will also usually contain minor amounts of additives, such as substances that enhance isotonicity and chemical stability. Examples of buffers include phosphate buffer, bicarbonate buffer and tris buffer, while examples of preservatives include thimerosal, m- or o-cresol, formalin and benzyl alcohol. Standard formulations will either be liquid injectables or solids which can be taken up in a suitable liquid as a suspension or solution for injection. Thus, in a nonliquid formulation, the vehicle may comprise dextrose, human serum albumin, preservatives, etc., to which sterile water or saline could he added prior to administration.

Various adjuvants are known in the art which can also Do employed in the vaccine formulations of the present invention; e.g., Freund's adjuvant, Avridine, aluminum salts [$Al(OH)_3$, $AlPO_4$, $Al_2(SO_4)_8$], $Ca_3(PO_4)_2$, saponin, DDA, Pluronics, oil-in-water emulsions (containing, e.g., Avridine, dextran sulphate, Emulsigen PLUS or vitamin E) and water-in-oil emulsions (containing, e.g., polysorbate 80). The selection of the appropriate adjuvant and its concentration in the vaccine composition is within the skill of the art.

Many protocols for administering the vaccine composition of the present invention to animals are within the skill of the art. The preferred route of administration is parenteral, particularly intramuscular. The concentration of the antigen(s) in the vaccine composition is selected so that an effective dose is presented in the bovine host to elicit antibodies to the polypeptide neutralizing epitopes. Within wide limits, the dosage is not believed to be critical. Typically, the vaccine composition is administered in a manner which trill deliver between about 1 to about 1,000 μg of the subunit antigen in a convenient volume of vehicle (e.g., about 1-10 ml). Preferably, the dosage in a single immunization will deliver from about 1 to about 500 μg of subunit antigen, more preferably about 5-10 μg to about 100-200 μg (e.g., 10-100 μg). It may also be preferred, although optional, to administer a second, booster immunization to the animal several weeks to several months after the initial immunization. To insure sustained high levels of protection against disease, it may be helpful to readminister a booster immunization to the animals on a periodic basis.

The antigen can be produced from protein recovered from virus or virus-infected cells, or cells expressing the recombinant glycoproteins. For example, purified virus or virus-infected cells can be disrupted or lysed and subjected to immunoadsorbent chromatography to purify gI, gIII or gIV. See, e.g., van Drunen Littel-van den Hurk et al. (1985) Virology 144: 204-215. The production Of monoclonal antibodies is within the skill of the art. See, e.g., van Drunen Littel-van den Hurk et al. (1984), supra; Okazaki at al. (1987), supra. Briefly, a mammal, sub as a mouse, is immunized with either purified virus or the purified viral glycoprotein of interest (e.g., SDS-PAGE purified) and antibody-producing B lymphocytes recovered. Typically, these B lymphocytes are then fused with a continuous cell line to produce an immortal antibody-producing cell line; i.e., a hybridoma, trioma, etc. Immortal, antibody-producing call lines can also be created by techniques other than fusion, such as direct transformation of B-lymphocytes with oncogenic DNA, or transfection with Epstein-Barr virus. See, e.g., M. Schreier et al. (1980) Hybridoma Techniques; Hammerling et al. (1981) Monoclonal Antibodies and T-Cell Hybridomas; Kennett et al. (1980) Monoclonal Antibodies; see also U.S. Patent Nos. 4,341,761; 4,399,121; 4,427,783; 4,444,887; 4,451,570; 4,466,917; 4,472,500; 4,491,632; 4,493,890. Native BHV-1 proteins which are immunopurified can be used in their entirety as subunit antigens, or fragments of the entire proteins containing the neutralizing epitopes can be employed as subunit antigens.

Non-native BHV-1 polypeptides can be produced by a number of methods. For example, oligopeptides containing neutralizing epitopes can be prepared synthetically by known techniques. See, e.g., U.S. Patent No. 4,735,896. It is preferred, however, to prepare the non-native polypeptide subunit antigens by recombinant DNA methods.

Recombinant polypeptide subunit antigens are produced according to the present invention by constructing an xpression cassette and transforming a host cell therewith to provide a cell line or culture capable of expressing the subunit antigen which is encoded within the expression cassette. The first step in constructing the expression cassett is to obtain a coding sequence for the glycoprotein or glycoprotein epitopes of interest. Thus, coding sequences can either be prepared directly by synthetic methods based on the disclosed sequence (or equivalent sequences encoding the same amino acids), or by using the disclosed sequence to design oligonucleotide probes to clone coding sequence using known techniques. See, e.g., Mayfield et al. (1983), supra. The coding sequence can be comprised entirely of BHV-1 glycoprotein-encoding sequences, or such glycoprotein sequences can be fused to other sequences (e.g., leader sequences) so that a fusion protein is encoded. See, e.g., U.S. Patent Nos. 4,431,739; 4,425,437; 4,338,397. Synthetic coding sequences will also allow for the convenient construction of coding sequences which express BHV-1 glycoprotein analogs or "muteins". Alternatively, coding sequences for muteins can be prepared by site-directed muta-

genesis of native BHV-1 nucleotide sequences. The techniques of site-directed mutagenesis are known in the art.

Once an appropriate coding sequence for the antigen has been prepared or isolated, it can be cloned into any suitable vector or replicon. Numerous cloning vectors or replicons are known to those of skill in the art, and the selection of an appropriate cloning vector is a matter of choice. Examples of recombinant DNA vectors for cloning and host cells which can be transformed include various bacteriophage lambda vectors (E. coli), pBR322 (E. coli), pACYC171 (E. coli), pKT230 (gram-negative bacteria), pGV1106 (gram-negative bacteria), pLAFR1 (gram-negative bacteria), pME290 (non-E. coli gram-negative bacteria), pHV14 (E. coli and Bacillis subtilis), pBD9 (Bacillis), pIJ61 (Streptomyces), pUC6 (Streptomyces), actinophage dC31 (Streptomyces), YIp5 (Saccharomyces), YCp19 (Saccharomyces), 2-micron plasmid (Saccharomyces), and bovine papilloma virus (mammalian cells). See, generally, DNA Cloning, vols I & II, supra; Maniatis et al., supra; Perbal, supra.

To complete construction of expression cassettes, the coding sequence as described above for the antigens is then operably linked to control sequences (e.g., a promoter, etc.), so that the DNA sequence encoding the subunit antigen is transcribed into messenger RNA in the host cell transformed by the expression cassette. It is within the skill of the art to operably link the subunit antigen coding sequence to appropriate control sequences in order to bring about transcription and translation. In general, the coding sequence will be downstream from the promoter sequence and any expression regulatory regions, such as enhancers or operator sequence. If the subunit antigen coding sequence is linked to a heterologous coding sequence or start codon, then it is important to place the subunit antigen coding sequence in reading frame with the latter. If the intended expression host is procaryotic, then it will also be necessary to include a ribosome binding site among the upstream control sequences. Downstream operably linked control sequences will usually comprise a transcription termination sequence, and a polyadenylation signal (for mammalian expression hosts).

When the intended expression host is a procaryotic or yeast cell, the promoter and other control sequences will necessarily be heterologous to the subunit antigen coding sequence. If the selected expression host cell is a mammalian cell, the control sequences can be homologous BHV-1 sequences, or preferably heterologous mammalian control sequences. The expression cassette can be constructed, for example, as a discrete molecular entity flanked by convenient restriction sites, or it can be constructed by inserting the coding sequence into a previously constructed expression vector with an appropriate insertion site.

A number of procaryotic expression vectors are known in the art. See, e.g., U.S. Patent Nos. 4,440,859; 4,436,815; 4,431,740; 4,431,739; 4,428,941; 4,425,437; 4,418,149; 4,411,994; 4,366,246; 4,342,832; see also U.K. Publication Nos. GB2,121,054; GB2,008,123; GB2,007,675; and European Publication No. 103,395. The preferred procaryotic expression vectors are those for E. coli. Other preferred expression vectors are those for use in eucaryotic systems. Yeast expression vectors are also known in the art. See, e.g., U.S. Patent Nos. 4,446,235; 4,443,539; 4,430,428; see also European Publication Nos. 103,409; 100,561; 96,491.

One of the preferred expression hosts of the present invention are mammalian cells. Various cell lines and expression vectors are known in the art. Examples of appropriate mammalian expression hosts include kidney cell lines (e.g., CV-1 monkey kidney cell lines), fibroblast cell lines (e.g., human, murine or chicken embryo fibroblast cell lines), Chinese hamster ovary (CHO) cells, HeLa cells, mouse NIH/3T3 and/or LMTK$^-$cells. It is also known to express heterologous proteins in myeloma cell lines employing immunoglobulin promoters. See, e.g, Banerjee et al. (1983) cell 33:729-740; U.S. Patent No. 4,663,281. The selection of a mammalian cell line is not critical, and is within the skill of the art. Various mammalian expression vectors employing viral promoters (e.g., SV40 early region promoter, Rous sarcoma virus, LTR promoter, etc.) are also well known in the art. See, e.g., Pachl et al. (1987), supra; Gorman et al. (1982) Proc. Natl. Acad. Sci. USA 79:6777-6781; Southern et al. (1982) J. Mol. App. Genet. 1:327-341; PCT Publication No. WO87/02062.

Preferred eucaryotic expression vectors are those employing the vaccinia virus, the SV40 virus, or the Rous sarcoma virus, which are also well known in the art. See, e.g., Mackett et al. (1984) J. Virol. 49:857; DNA Cloning, vol. II, pp. 191-211, supra; PCT Publication No. WO86/07593; Chakrabarty et al. (1985) Mol. Cell. Biol. 5:3403.

Another preferred embodiment of the present invention is the expression of recombinant BHV-1 polypeptides in insect cells using viral vectors, such as baculovirus. For example, high levels of expression have been achieved with vectors based on Autographa californica nuclear polyhedrosis virus (AcNPV) in Spodoptera frugiperda cells. See, e.g., Smith et al. (1983) J. Virol. 46:584-593; U.S. Pat. App. Serial No. 07/092,120, supra; Canadian Pat. App. Serial No. 545,803, supra.

Generally, a host (cell) which has been stably transformed by an expression cassette for the subunit antigen is selected to produce the recombinant polypeptide. A stably transformed host is one wherein the expression cassette has integrated into the host cell's chromosome. In the case of bacteria, yeast or mammalian expression hosts or the like, it may be preferred to select expression hosts which maintain the cassette on a non-integrating episomal element, such as a plasmid. The subunit antigen is produced by growing host cells transformed by the expression cassette under conditions which cause the expression of biologically active subunit antigen polypeptide. The appropriate conditions to bring about expression are well known in the art, and will depend primarily on the expression system and host selected. The subunit antigen polypeptide may be isolated from the host cells and purified. If the expression system secretes the

subunit antigen, then the polypeptide can be purified directly from the growth media. If antigen is not secreted, however, it may be necessary to disrupt the host cells and purify the subunit antigen polypeptide from the cellular lysate. Various purification techniques, such as HPLC and immunoaffinity chromatography, are known, and the selection of the appropriate purification and recovery method is within the skill of the art.

It is known that BHV-1 can be immunosuppressive. This could interfere with the effectiveness of other bacterial or viral vaccines administered concurrently with, or within a few days of BHV-1 vaccine. However, it has been discovered that vaccination with BHV-1 gIV and/or truncated BHV-1 gIV does not have an immunosuppressive effect on other bacterial or viral vaccines. Accordingly, subunit gIV can be used in conjunction with other vaccines without fear of causing reduced immune responses to them. Any bovine bacterial or viral vaccine reducing or preventing infection can be the second vaccine. Such materials are well known in the art and include but are not limited to vaccines against Pasteurella haemolytica, Haemophilus somnus, parainfluenza virus, coronavirus, rotavirus, adenovirus, bovine respiratory syncytial virus, bovine diarrhea virus and the like. Thus, a wide variety of co-infections can be co-treated.

Accordingly, the invention also includes a method for co-treating or preventing a BHV-1 infection and a second infection in a bovine host which comprises administering to the bovine host a therapeutically effective amount of (1) a vaccine composition of BHV-gIV and (2) a vaccine against the second infection and compositions which comprise (1) and (2).

An alternative route of administration involves gene therapy or nucleic acid immunization. Thus, nucleotide sequences (and accompanying regulatory elements) encoding the subject proteins can be administered directly to a subject for in vivo transcription and translation thereof. Alternatively, gene transfer can be accomplished by transfecting the subject's cells or tissue ex vivo and reintroducing the transformed material into the host. DNA can be directly introduced into the host organism, i.e., by injection (see, International Publication No. WO90/11092; and Wolff et al., Science(1990) 247:1465-1468). Liposome-mediated gene transfer can also be accomplished using known methods. See e.g., Hazinski et al., Am. J. Respir. Cell Mol. Biol. (1991) 4:206-209; Brigham et al., Am. J. Med. Sci. (1989) 298:278-281; Canonico et al., Clin. Res. (1991) 39:219A; and Nabel et al., Science (1990) 249:1285-1288. Targeting agents, such as antibodies directed against surface antigens expressed on specific cell types, can be covalently conjugated to the liposomal surface so that the nucleic acid can be delivered to specific tissues and cells susceptible to BHV-1 infection.

Diagnostic Assays for BHV-1 Antibodies

The recombinant antigens of BHV-1 gI, gIII and/or gIV can be used as substrate reagent in immunoassays to identify antibodies to BHV-1 gI, gIII and/or gIV in a sample, e.g., blood, from a bovine host as one means of determining if the bovine host is infected with BHV-1 and to determine the concentration of the antibodies in the sample. The immunoassays in which the recombinant antigens of BHV-1 gI, gIII and/or gIV can be used include, but are not limited to, radioimunoassay, competition immunoprecipitation, enzyme-linked immunoadsorbent assay, immunofluorescence assay and the lee. Detection is convenient, rapid, sensitive and specific. The recombinant antigen: of BHV-1 gI, gIII and/or gIV are used in assay compositions in a concentration sufficient to form a detectable complex with the antibodies. The BHV-1 antigens can be mixed with or attached to a suitable matrix (support) or carrier, such as a latex particle or plastic microtiter plate or the like. They can also be conjugated with an enzyme, dye, radio-labelled or the like, depending upon what immunological method is used. The details of conducting various types of immunoassays is well known in the art and also described in Tyssen, P., "Laboratory Techniques in Biochemistry and Molecular Biology, Practice and Theory of Enzyme Immunoassays" (Ed. R.H. Burton and P.H. van Knippenberg, the disclosures of which are incorporated by reference. Accordingly, the invention includes a method for determining the presence or absence of or concentration of antibodies for BHV-1 in a sample by employing an immunoassay, the immunoassay characterized by using recombinant antigenic BHV-1 gI, gIII and/or gIV reactive with BHV-1 antibodies as a reagent in the immunoassay, whereby a complex of the BHV-1 antibodies and the recombinant antigenic BHV-1 gI, gIII and/or gIV is formed, and determining the presence or absence of or concentration of the complex formed as indicative of the presence or absence of or concentration of the antibodies.

Described below are examples of the present invention which are provided only for illustrative purposes. The examples are not intended to limit the scope of the present invention in any way, as numerous embodiments within the scope of the claims will be apparent to those of ordinary skill in the art in light of the present disclosure. Those of ordinary skill in the art are presumed to be familiar with (or to have ready access to) the references cited in the application, and the disclosures thereof are incorporated by reference herein.

C. Experimental

EXAMPLES

I

This example demonstrates the protection of cattle immunized with subunit vaccines made from purified BHV-1 glycoproteins.

I.A. Materials and Methods

I.A.1. Virus and Bacteria

Strains P8-2 and 108 of BHV-1 were propagated in Georgia bovine kidney cells as described previously. Babiuk et al. (1975) Infect. Immun. 12:958-963. For virus challenge of animals strain 108 was used, whereas for glycoprotein isolation the P8-2 strain was used.

A culture of Pasteurella haemolytica (biotype A, serotype 1) was prepared as described previously. Bielefeldt Ohmann et al. (1985) J. Infect. Dis. 151:937-947. In each case, the bacterial challenge was in the log phase of growth and had a titer of 1 to 2 x 10^9 CFU/ml.

I.A.2. Monoclonal Antibodies and Immunoadsorbent Purification

Monoclonal antibodies against gI, gIII, and gIV were produced as described previously. van Drunen Littel-van den Hurk et al. (1984), supra. Clones 1E11-1F6, 1D6-G11 and 1G6-2D9 which recognize gI, gIII, and gIV, respectively, were selected to prepare immunoadsorbent columns.

Purification of IgG fractions of monoclonal antibodies was carried out using protein A-Sepharose CL-4B (Pharmacia Montreal, Quebec). L'Italien in Method of Protein Microcharacterization, pp. 279-314 (J.E. Shively ed. 1986). Monoclonal IgG was eluted from the protein A-Sepharose column with 50 mM triethylamine and was dialyzed thoroughly against 0.1 M HEPES, pH 7.5 (coupling buffer: CB). The purified IgG was linked to activated Affigel-10 (Bio-Rad Laboratories, Mississauga, Ontario) at 5 mg protein/ml gel, according to the manufacturer's instructions.

Glycoproteins gI, gIII, and gIV were purified from virus-infected cell lysate as previously described (van Drunen Littel-van den Hurk et al. (1985) Virology 144:216-227). Twenty-four hours postinfection, at a m.o.i. of 1, cultures were harvested and centrifuged at 1000 rpm to obtain infected cell pellets. Cells were resuspended in 1% Nonidet-P40 (NP-40) and 1% sodium deoxycholate (DOC) in 0.10 M Tris-hydrochloride, 0.15 M NaCl, (pH 7.5) and used as starting material for purification.

Immunoadsorbent columns with specificities for gI, gIII,and gIV, respectively, were prepared. After passage of the sample over the column in sample application buffer, the column was exchanged with 1 vol of fresh sample application buffer prior to washing with 2 vol of wash buffer [100 mM Tris, 500 mM NaCl, 1% NP-40 (pH 7.5)]. The wash buffer was displaced from the column with 2 vol of water prior to elution of the specifically bound antigen with 50 mM triethylamine. The eluted fractions were monitored by removing 5-50 µl collected fraction and performing a nonquantitative Bradford assay. Those fractions that contained protein were then directly concentrated for further analysis. The column was reequilibrated in sample application buffer for reuse or stored in sample application buffer plus 0.02% thimerosal. Columns prepared, used, and stored in this way have retained significant activity for almost a year.

I.A.3. Immunization and Pathogen Challenge

Purified glycoproteins were formulated with Avridine (N,N-dioctadecyl-N,N-bis) (2-hydroxylethylpropanediamine) as follows: 150 mg of Avridine was dissolved in 1 ml of absolute EtOH and then combined with 90 µl Tween 80 by thorough mixing. Next, 4.7 ml of Intralipid were combined with Avridine/EtOH and thoroughly mixed by vortexing. 4.0 mls of biological buffer, e.g. Hanks' buffered salt solution or PBS were added to the solution to complete the adjuvant preparation. The vaccine was prepared by mixing equal volumes of antigen and adjuvant solutions such that each animal received a dose of 100 µg of glycoprotein + 15 mg of Avridine in a 2 ml volume.

Groups of five animals each were immunized intramuscularly with the above preparations. Twenty-one days later animals were boosted and then challenged 3 weeks after booster immunization. Control unvaccinated calves were immunized with Avridine (adjuvant alone). A further control group was immunized with a commercial killed virus vaccine (Triangle 3, Fort Dodge Laboratories, Iowa) as recommended by the manufacturer. Blood samples were taken from animals at 10-day intervals for assessment of antibody responses.

Following immunization, animals were transported into an isolation pen and examined clinically, and rectal temper-

atures were recorded and blood samples were collected for various immunological assays to establish baseline immunological activity. The calves were then individually exposed to an aerosol of BHV-1, followed 4 days later with P. haemolytica. In each case, the aerosol was generated by a DeVilbiss Nebulizer, Model 65 (DeVilbiss, Barry, Ontario, Canada). Treatment was for 4 min in the case of the virus and 5 min with P. haemolytica as described previously. Bielefeldt Ohmann et al. (1985), supra.

I.A.4. SDS-PAGE, Western Blot, ELISA and ADCC

Sodium dodecyl sulfate (SDS)-polyacrylamide gel electrophoresis (PAGE) was carried out in 7.5% discontinuous slab gels under reducing conditions, as described previously (van Drunen Littel-van den Hurk et al. (1984), supra; Laemmli (1970) Nature (London) 227:680-685).

The Western blotting technique was performed as described previously (van Drunen Littel-van den Hurk et al. (1984), supra). After electrophoresis, virus lysates were electrophoretically transferred to nitrocellulose sheets. Subsequently, the instructions for use of the Bio-Rad (Mississaugo, Ontario) immunoblot assay kit were followed.

In order to determine the antibody responses of cattle immunized with purified glycoproteins, the ELISA was performed essentially as described previously (van Drunen Littel-van den Hurk et al. (1984), supra). However; affinity-purified, peroxidase-conjugated rabbit anti-bovine IgG (Zymed) at a dilution of 1:3000 was used as the detecting antibody.

The neutralization titers of the bovine sera were determined as described previously (Babiuk et al. (1975), supra). To determine complement-enhanced neutralization, guinea pig serum (1:40 final dilution) was added to the virus-antibody mixture. The titers were expressed as the reciprocal of the highest dilution of antibody which caused a 50% reduction of plaques relative to the virus control.

ADCC assays were performed in microtiter plates as described previously (Babiuk et al. (1975), supra). The ratio of effector cells (polymorphonuclear cells) to target cells (BHV-1-infected, ^{51}Cr-labeled GBK cells) was 50:1. Controls consisted of BHV-1-infected GBK target cells plus anti-BHV-1 serum or targets with polymorphonuclear cells in the absence of antibody.

I.A.6. Clinical Evaluation and Necropsy

The clinical evaluations were performed at the same time each day by two independent investigators who were uninformed about the specific treatments of the individual animals. The parameters evaluated included depression, appetite, fever, conjunctivitis, rhinitis, mouth-breathing, tracheitis, and pneumonia. In each case a score of 0 was assigned to healthy animals. Clinical scores of 1-4 were assigned to sick animals for each individual parameter as follows: 4, severe; 3, marked; 2, moderate; 1, mild. Total clinical scores for each animal are the sums of scores for each parameter.

Postmortem examinations were done on animals that died or were euthanized during the experiments. The nasal passages, larynx, trachea, and lungs were examined and photographed. Viral and bacterial lesions were recorded. The extent of pneumonia was assessed by a numerical method developed by Thomson et al. (1975) Canad. J. Comp. Med. 39:194-207. The pneumonic lesions in each lung lobe (except for the accessory lobe) were graded from 0 to 5 according to the amount of tissue involved. Total scores for seven lung lobes ranged from 0 to a theoretical maximum of 35 if the entire lung was affected.

I.A.7. Leukocyte Function

To study post-BHV-1-challenge leukocyte function, venous blood was collected into syringes containing citrate dextrose. The blood was centrifuged at 1000 g for 20 min, the buffy coat was collected, and the peripheral blood mononuclear leukocytes (PBL) were further purified on Ficoll-Hypaque as described previously. Bielefeldt Ohmann et al. (1985), supra. The polymorphonuclear neutrophils (PMN) were isolated from the original pellet by lysis of the erythrocytes as described previously. The viability of both PBLs and PMNs was greater than 99% as determined by trypan blue exclusion.

(i) Functional Analysis of PBL. Lectin-driven lymphocyte proliferation was assayed as described previously. Id. Briefly, 1 x 10^5 PBL were added into quadruplicate wells of a flat-bottomed microtiter plate (Nunc, Roskilde DK) in a final volume of 200 µl of RPMI 1640 plus 5% fetal bovine serum, 50 mM HEPES, and 25 mg gentamycin (all media components are from Grand Island Biological Co., Grand Island, NY). Lectins, phytohemagglutinin (PHA), and concanavalin A (Con A, Calbiochem, La Jolla, CA) were added to the cultures. The cultures were incubated for 72 hr and labeled with [methyl-^{3}H]thymidine (H^3-Tdr) (Amersham Co., Oakville, Ontario) during the last 16-18 hr of incubation. The amount of radioactivity incorporated by PBLs was quantitated by liquid scintillation counting.

(ii) Functional Analysis of PMNs. Chemotaxis of PMNs was measured using microchemotaxis chambers. Gee et

al. (1983) Proc. Natl. Acad. Sci. USA 80:7215-7218. Briefly, 25 µl of the chemoattractant was added to the bottom wells of the chemotaxis chamber, whereas the top chamber wells contained 45 µl of PMNs. The chemotaxis chambers ware incubated for 2 hr in a humidified CO_2 atmosphere at 37°C. After incubation, the membranes were removed and nonmigrating cells were scraped from the upper surface. Membranes were fixed, stained with Giemsa, and examined microscopically for the presence of migrating cells. Cell counts are presented as the mean counts of three representative high-power microscope fields.

Luminol-enhanced chemiluminescence was measured by the method of Abramson et al. (1982). Briefly, 2 x 10^7 cells wore added to vials containing 5 ml of Hank's balanced salt solution, 400 µl of opsonized zymosan, and 20 µl of luminol. Immediately upon addition of the cells, the reaction was followed over time using a Packard Picolite 6500 Luminometer (United Technologies Packard, Downers Grove, IL). Results are plotted as CPM/10^7 cells at the peak of the response which occurs at 45 min.

Superoxide anion generation and release were measured by the superoxide dismutase (SOD) inhibitable reduction of ferracytochrome C as described previously. Johnson et al. (1978) J. Exp. Med. 148:115-127. All samples were assayed in duplicate and in suspension in a final volume of 1 ml. The samples were incubated for 45 min at 37°C. The reaction was terminated by transferring 1 ml aliquots to an ice bath followed by centrifugation. The cytochrome c reduction was monitored on a spectrophotometer at 550 nm. The OD value was then converted to nm O_2/cell.

II

This example demonstrates the production of non-native BHV-1 subunit antigens in recombinant vaccinia virus vectors.

II.A. Recombinant Production of gIV in a Vaccinia Vector

II.A.1. Construction of the pVVSL-1 Insertion Vector

The pVVSL-1 insertion vector was constructed as depicted in Figures 2 and 3. Vaccinia virus vectors are known, such as VAC-I and VAC-III deposited as ATCC VR-2223 and VR-2224, respectively July 22, 1988. Specifically, the pVV-1 expression vector was derived from the pGS-20 plasmid (van Drunen Littel-van den Hurk et al. (1989) J. Virol. 63:2159-2168). pGS-20 was digested with XhoI and AvaI, treated with DNA poll Klenow fragment to blunt the ends and then ligated. This process resulted in the deletion of a 2,200 bp fragment and the production of pVV-1 (Figure 2).

pVVSL-1 was then constructed from elements of pVV-1 and a series of four synthetic oligonucleotides representing an adenine rich region, a spacer and a consensus sequence from the vaccinia virus late gene promoter. (This sequence was based on a sequence described by Davison and Moss (1989) J. Mol. Biol. 210:771-784.) A 3,080 bp EcoRI-PstI fragment and a 1,700 bp XmaI-PstI fragment were isolated from restriction enzyme digests of pVV-1. The fragments were then ligated together with the four oligonucleotides to form pVVSL-1. The pVVSL-1 has two unique cloning sites; BglII or SmaI (Figure 3).

II.A. 2. Insertion of the Full-Length BHV-1 gIV Gene into pVVSL-1

The procedures for gene insertion and recombinant vaccinia virus recovery were the same as that described for pGS-20. (See, van Drunen Littel-van den Hurk et al. (1989) J. Virol. 63:2159-2168.)

The BHV-1 gIV sequence shown in Figure 1 was digested with MaeI restriction endonuclease. The resulting MaeI sites at sequence positions 42 and 1344 were converted to BglII sites using commercially obtained oligonucleotide linkers (Pharmacia). The resulting BglII adapted BHV-1 gIV gene was then cloned into the BglII cloning site of pVVSL-1 to yield the expression vector pVV-1/gIV (Figure 4).

II.A.3. Insertion of a Truncated BHV-1 gIV Gene into pVVSL-1

The gene for BHV-1 gIV was modified to incorporate a stop codon in the reading frame immediately preceding the putative membrane spanning region of the mature protein (Figure 1). This modification of the gene results in the early termination of translation and secretion of the truncated protein. This system eliminates the requirement for extensive downstream processing that is associated with the production of antigens that are associated with membranes, and causes an up to tenfold increase in product yield.

The BglII adapted gene for BHV-1 gIV was partially digested with SacII. The SacII site at position 1154 (Figure 1) was then converted into a XhoI site using commercially obtained oligonucleotide linkers (Pharmacia). A second synthetic oligonucleotide linker was then inserted at the XhoI site to yield an in-frame stop codon. The resulting modified

BHV-1 gIV gene was then cloned into the BglII cloning site of pVVSL-1 to yield the expression vector pVV-1/gIVt (Figure 5).

II.A.4. Purification of Recombinantly Expressed gIV

BSC-1 cells were cultured in MEM containing 10% fetal bovine serum. Confluent monolayers were infected with the recombinant vaccinia, expressing either full-length or truncated and secreted BHV-1 gIV at a multiplicity of 0.1. 72 hours after infection or at the appearance of total cytopathic effect, the recombinant gIV was harvested.

For full-length gIV, the cells were scraped from the surface of the culture flasks into the growth media, which was then centrifuged (1000g for 20 min) and the cell pellet collected. The cells were disrupted with detergent and further processed as previously described.

Truncated gIV was collected by harvesting the media from the culture flasks. Cell debris was removed by centrifugation at 1000g for 20 min. The clarified media was frozen at -70°C until processing. After thawing, the media was filtered through a 0.45 micron filter. The detergents, Nonidet P40 and Na Deoxycholate, were then added to the filtrate to final concentrations of 0.1%. The truncated gIV was then purified by affinity chromatography through BHV-1 gIV specific columns, as has been described previously.

III

This example demonstrates the production of non-native BHV-1 subunit antigens using a Baculovirus system.

III.A. Materials and Methods

III.A.1. Cells, Viruses and Antibodies

S. frugiperda (SF9) cells were grown and maintained in TNM-FH medium (GIBCO) containing 10% fetal bovine serum as described by Summers and Smith (Summers, M.D., and Smith, G.E., "A manual of methods for baculovirus vectors and insect cell culture procedures" Texas Agricultural Experiment Station bulletin no. 1555 (1987). Texas Agricultural Experiment Station, College Station, Tex.). Virus stocks of the wild type AcNPV and recombinant baculoviruses were prepared in SF9 cells as described by Summers and Smith (supra). Monoclonal antibodies specific for gIV were developed and characterized by van Drunen Littel-van den Hurk et al. (1987) Virology 160:465-472; and Hughes et al. (1988) Arch. Virol. 103:47-60. The gIV-specific monoclonal antibody mixture used for identification of recombinant gIV consisted of equivalent amounts of 136 (epitope Ia), 9D6 (epitope Ib), 3E7 (epitope II), 10C2 (epitope IIIa), 4C1 (epitope IIIb), 2C8 (epitope IIIc), 3C1 (epitope IIId), and 3D9S (epitope IV).

III.A.2. Insertion of BHV-1 Glycoproteins into the AcMNPV Transfer Vector

The gIV glycoprotein gene was isolated from a subclone of pSD9 as a 1.3 kb MaeI fragment (Tikoo, S.K. et al. (1990) J. Virol. 64:5132-5142, which was blunt end repaired and inserted into the plasmid pRSV cat (Fitzpatrick, D.R. et al. (1988) J. Virol. 62:4239-4248). The 1.3 kb BglII fragment was then subcloned into the BamHI site of the baculovirus transfer vector pVL941 (Luckow, V.A. and Summers, M.D. (1989) Virology 170:31-39). Plasmid DNA was prepared by alkaline lysis and cesium chloride gradient centrifugation by standard methods. After transformation of E. coli JM105, colonies appearing on LB agar containing 100 μg of ampicillin per ml were inoculated into L broth containing ampicillin (50 μg/ml) and incubated at 37°C overnight with vigorous shaking. Small scale preparations of plasmid from each colony were prepared, and the presence of the gIV gene was confirmed by digestion with endonucleases AvaI and EcoRV. A single clone was identified containing the gIV gene in the desired orientation and designated pVLgIV. Clone pVLgIV was inoculated into 500 ml. of L broth containing ampicillin; after 24 h at 37°C, the plasmid was prepared by alkaline lysis and further purified by equilibrium centrifugation on CsCl.

A modified BHV-1 gIV gene, as described in Example II.A.3, that produces a truncated form of gIV, was digested with BglII, the fragment isolated and subcloned into the BamHI site of the baculovirus transfer vector pVL941. This construct was named pVLgIVt.

The gI glycoprotein gene contained in plasmid pgB complete, described in Example II.B.1 of U.S. patent 5,151,267, was digested with BglII and BamHI and inserted into the BamHI site of the baculovirus transfer vector pVL941.

The gIII glycoprotein gene contained in plasmid p113R1 Bgl 3.0, as described in Example II.B.1 of U.S patent 5,151,267, was transferred to the BamHI site of baculovirus transfer vector pVL941 as an EcoRI + BamHI subfragment. This construct was designated pVLgIII.

III.A.3. Transfection and Selection of Recombinant Viruses

After two cycles of ethanol precipitation, purified plasmid was mixed with an equal amount of A. californica viral DNA and used to transfect subconfluent monolayers of SF9 cells as outlined by Summers and Smith (supra). After incubation at 28°C for 5 days, the supernatant was serially diluted and inoculated onto confluent monolayers of SF9 cells. After 1 h, an overlay consisting of TNM-FH medium containing 6% fetal bovine serum and 1.5% low-gelling-temperature agarose was added, and the plates were incubated at 28°C for 5 days. Recombinant baculoviruses were identified by plague hybridization essentially as outlined by Summers and Smith (supra). The polyhedrin-negative recombinants were plaque purified three to four times on SF9 cells to remove contaminating wild-type baculoviruses.

III.A.4. Preparation of Cell Lysates

To analyze expression of recombinant gIV confluent monolayers of SF9 cells on 35 mm petri dishes were infected with individual polyhedrin-negative recombinants at a multiplicity of infection of 5 and incubated for 48 h at 28°C. The cells were scraped into phosphate-buffered saline (PBS), pelleted at 150 x g for 1 min, and suspended in 50 µl of RIPA buffer (0.02 M Tris hydrochloride [pH 8.0], 0.15 M NaCl, 1% sodium deoxycholate, 1% Nonidet P-40, 10 mM EDTA, 10 mM phenylmethylsulfonyl fluoride). The postnuclear supernatant was collected, combined with reducing electrophoresis sample buffer, and boiled for 2 min.

IV

This example demonstrates the production of non-native BHV-1 subunit antigens in E. coli vectors.

IV.A. Cloning and Expression of the BHV-1 gI Gene in E. coli

A BHV-1 genome library of BHV-1 strain Cooper as represented in 12 HindIII fragments cloned in to pBR322, was screened according to the methods of Southern, using probes corresponding to HSV-1 gB and the pseudorabies virus (PRV) gB gene counterpart. A single clone, pSD106, was found to bind to the probes.

In order to specify the actual coding sequences of the BHV-1 gI gene, a detailed restriction map was constructed for pSD106. The application of the techniques of Southern using separate probes specific for the HSV-1 gB amino and carboxy-termini, located the BHV-1 gI gene within a KpnI - SalI sub-fragment of pSD106 (pSD106 KpnI-SalI; Figure 6).

It is not expected that foreign viral proteins produced in E. coli would be folded into a configuration that mimics the protein in the native virus particle. Therefore, the most active immunogen obtained from bacterially expressed genes is likely to be composed of a contiguous stretch of amino acids rather than one which requires the positioning of two or more contiguous sequences of amino acids (i.e., tertiary structure). An additional limitation is that E. coli will not process pre gI to gIb + gIc. Thus, it was hypothesized that the optimal formulation of bacterially expressed gI would be composed of gIb and gIc, expressed individually and then utilized either separately or in combination.

To construct a clone expressing the amino terminus of mature gIb + gIc, the pSD106 KpnI - SalI fragment was cut with ApaI and the lengths of the ApaI fragments randomized by treatment with Bal31 exonuclease. Any asymmetric fragment\ends produced by imprecise Bal31 activity were blunted by Klenow fill-in reactions. The ApaI digested plasmid was then cut with XmaI and the population of fragments carrying sequences encoding the amino terminus of gIb were isolated from LMP agarose gels as a 600-520 bp smear. This fragment sub-population was then ligated to the HpaI - XmaI sites of polink 26. Polink 26 was a modified form of pBR328 and contained a synthetic oligonucleotide inserted into the EcoRI and SalI sites. The oligonucleotide contained restriction enzyme sites in the following order: EcoRI, XbaI, BglII, BalI, HpaI, ClaI, HindIII, KpnI, BamHI, SmaI, SphI, SacI, XhoI, SalI.

An insert from the clone bank of the amino terminus of gI was isolated by BglII and SmaI digestion of pBHB5' and transferred to the BglII plus SmaI sites of the E. coli expression vector pHK414. The resulting clone was named pRed30. To complete the construction of the gIb coding sequence, SmaG was isolated as a 775 bp XmaI fragment from pSd106 KpnI - SalI and was ligated to the XmaI site of pRed30 to produce pgp11:βgal. This plasmid was transformed into the E. coli strain NF1829, produced a gp11:β-galactosidase fusion protein of approximately 175k (gp11 is another designation of the gIb peptide). An unfused gIb peptide was made by the "gp11 complete" clone. "pgp11 complete" (Figure 7) was constructed by transferring the 1340 bp BglII - BamHI fragment from pgp11:βgal to the E. coli expression plasmid pGH346. The 1340 bp fragment carries the entire gIb coding sequence plus DNA encoding the first eight amino acids of gIb. In NF1829, "pgp11 complete" produc s a 60k protein which specifically reacts to BHV-1 gIb polyclonal sera and gIb specific monoclonal antibodies.

IV.B. Cloning and Expression of BHV-1 gIII gene in E. coli

The BHV-1 genomic library was screened by the techniques of Southern using probes specific for the coding sequence of the HSV-1 gC and the PRV gC homolog (PrV gIII). One of the HindIII clones, designated pSD113 (Figure 6), hybridized to both the probes. A restriction endonuclease map of the pSD113 plasmid was prepared in order to locate the region within the HindIII fragment which specifically encoded the BHV-1 gIII gene. By using a probe specific for the PRV gC gene homolog, the BHV-1 gIII gene was located within an approximately 2500 bp EcoRI - BglII subfragment of pSD113.

An E. coli clone expressing the carboxy-terminal two-thirds of the BHV-1 gIII gene was made in the following way. The pSD113 EcoRI - BglI subfragment of pSD113 was digested with XmaI and inserted into the XmaI site of the plasmid pJS413 to form pBHC3'. The pSD113 EcoRI - BglII subfragment of pSD113 was digested with PvuI and the PvuI asymmetric ends were treated with Klenow enzyme to blunt them. The PvuI digested plasmid was then cut with SacI, and the 1600 bp PvuI - SacI fragment containing the carboxy-terminus of the gIII was purified from LMP agarose gels. This fragment was ligated to SmaI plus SacI sites of plasmid ptac413 to produce p113Pvu/413. The extraneous sequences 3' to the stop codon were removed by replacing the 900 bp AvaI - SacI fragment from p113Pvu/413 with the 2220 bp AvaI - SacI fragment from BHC3'. The new plasmid "p113 Pvu end" carried 900 bp of BHV-1 gIII gene carboxy-terminus in frame to the reconstituted β-galactosidase gene. The E. coli strain NF1829 was transformed with this plasmid.

Upon induction with lactose, these cells produced approximately 5% of the total protein as a gIII related protein. The fusion product was collected as aggregates and solubilized in 10 mMol urea, pH 9.0. The solubilized protein was dialyzed against 10 mMol triethylamine, pH 9.0 to remove urea and then concentrated by Amicon filtration to a final concentration of 2 mgs/ml of BHV-1 protein. The concentrated gIII fusion protein was formulated with Freunds' Complete Adjuvant and injected intramuscularly to rabbits in 1 mg doses. The antisera raised in these rabbits was used to immunoprecipitate a BHV-1 infected cell extract and was found to specifically react with the gIII glycoprotein.

In an attempt to express the full-length BHV-1 gIII gene in E. coli, the expressor clone "113Pvu end" was extended to include all gIII coding sequences up to the NcoI site ("gIII complete"). This full-length clone failed to produce significant amounts of gIII protein. The simple removal of the signal sequence and/or addition of preferred E. coli codons upstream of the gIII sequences failed to improve expression. In order to produce the largest E. coli gIII expressor clone possible, and to avoid the apparent problem in expressing the amino terminal gene sequences, a library of gIII clones was generated with randomized amino termini. The E. coli plasmid "gIII complete", which does not express significant amounts of gIII protein, was digested with NcoI and then treated with Bal31 for varying lengths of time. NcoI cut at the ATG of the gIII gene and Bal31 treatment removed nucleotides starting from the NcoI cut ends to varying extents. The population of random sized fragments were treated with Klenow enzyme to blunt asymmetric ends and were then digested with BamHI. The population of NcoI - Bal31 - BamHI fragments ranging in size from 1530 bp to 1250 bp were isolated from LMP agarose and ligated to the SmaI - BamHI sites of pJS413. E. coli NF1829 was transformed with this ligation mixture and plated to MacKonkey's Agar. Putative expressor clones were picked as red colonies. The positive colonies were then tested for protein production by lactose induction and protein analysis by SDS-PAGE. Three clones were found to express gIII as a β-galactosidase fusion protein. The clones were found to differ in the amount of amino terminal sequence removed by the Bal31 treatment: losing 150, 250, and 350 bp, respectively. The gIII gene inserts were excised by BglII - BamHI digestion of the Bal31 expressor plasmids and then purified from LMP agarose gels. Each gIII carrying fragment was then ligated into the BglII - BamHI sites of the E. coli expressor plasmid GH435. pGH435 carries stop codons in each of the three possible reading frames immediately 3' to the BamHI insertion site. Therefore, expression of any insert at the BglII and BamHI sites would generate a nonfused peptide. The largest Bal31 clone, called pBHC150Δ (Figure 8), which had a deletion of approximately 150 bp at the amino terminus of gIII, makes a peptide of approximately 53K upon lactose induction. This plasmid is carried in the E. coli strain W3110F'Iq.

IV.C. Expression of Full-Length Mature BHV-1 gIV in E. coli

The BHV-1 genomic library clone pSD98 (Figure 6) was identified as carrying the gIV gene, in addition to several other putative BHV-1 genes. Restriction enzyme mapping of pSD98 mapped the gIV protein encoding sequences to a XmaII - XhoI fragment of this plasmid. pSD98 was digested with XmaI and XhoI, the fragment isolated and inserted into the plasmid polink 26 to produce p98XmaI - XhoI.

The construction of the gIV gene containing E. coli expression vector is depicted in Figure 9. The signal sequence does not appear in the mature gIV protein and does not contribute to immunogenicity of the glycoprotein. Therefore, the signal sequence was removed by making a synthetic oligonucleotide corresponding to the coding sequence of the first amino acid of the mature BHV-1 gIV gene (i.e., Leu) and extending to the SalI site 88 bp downstream from the start (ATG) of the gene (see Figure 1). An engineered HindIII asymmetric overhang was added immediately 5' to the Leu codon and a XmaI asymmetric end was added immediately 3' to the SalI site (see Figure 9). The HindIII and XmaI over-

hangs permitted ligation of the oligonucleotide into the HindIII plus XmaI sites of the E. coli expression vector pHK414. The resultant plasmid was called BHDsyn43 and is carried in the E. coli strain MC1066.

The amino-terminus of the gIV clone BHDsyn43 was extended by ligating the 590 bp BamHI - SalI fragment from p98Xma-XhoI to the SalI plus BamHI sites of the BHDsyn43. This ligation produced pBHD5' and carries the first 620 bps of the coding sequence for mature BHV-1 gIV. The pBHD5' was also maintained in the E. coli strain MC1066.

An E. coli clone expressing full length mature BHV-1 gIV was made by first transferring the gIV insert from pBHD5' carried in a 630 bp BglII - BamHI fragment, to the BglII - BamHI sites of the E. coli expression plasmid GH432. The carboxy terminal half of the gIV gene was then added by ligating the 640 bp XmaI fragment from pSD98 to the XmaI site in the new construction BHD5'/432. The plasmid pSD98 was part of the original BHV-1 genomic library BHV-1 strain Cooper (Figure 6). The library takes the form of 12 HindIII clones of the viral genome inserted into the pBR322. Plasmid pSD98 was identified as part of the gIV gene partially by its location in the "S" region of the BHV-1 genome, that corresponds to the location of the gD of other herpesviruses, e.g., HSV-1 and 2, PRV and EHV-1, and reactivity in Southern blots using a probe corresponding to the PRV gIV gene homologue.

The final BHV-1 gIV E. coli expressive plasmid is called pBHDsib (Figure 10) and was transformed in the E. coli strain W31104'Iq. Upon induction with lactose (2% final concentration), pBHDsib made a 58K protein which represented approximately 10% of the total protein produced by the clone. In a western blot assay, the 58K protein reacted specifically with anti-BHV-1 hyperimmune serum and the BHV-1 gIV specific monoclonal antibody 3D9.

An aggregate preparation from pBHDsib was solubilized in 50 mMol β-mercaptoethanol, 0.5% SDS pH 8.0. Doses containing 150 μg of the 58K solubilized protein were prepared in Freunds' Complete Adjuvant and administered to rabbits by intramuscular injection. Sera raised in these animals reacted specifically with a glycoprotein from BHV-1 infected cell extracts indistinguishable from gIV. When assessed for BHV-1 virus neutralizing activity in vitro, the rabbit sera was found to have a plague reduction titre of 1:128.

IV.D. Purification of Recombinant BHV-1 Glycoproteins

E. coli W3110F'Iq transfected with pBHDsib was cultured in L broth supplemented with ampicillin (50 μg/ml). Late log growth phase cultures were induced with either 2% lactose or 2 mM IPTG. Five hours after induction, the cultures were harvested, the cells pelleted by centrifugation (2000g for 20 min) and then mechanically disrupted. The aggregates were subsequently dispersed by treatment with 6M GuHCl and then dialyzed to reduce the GuHCl concentration to 2M.

The other BHV-1 qlycoproteins expressed in E. coli are similarly purified.

V

The following example illustrates the production of non-native BHV-1 subunit antigens in recombinant adenovirus vectors.

V.A. Expression of BHV-1 gIV Using Adenovirus Vectors

In one form, this expression system is based on human adenovirus serotype 5. The E1 and E3 regions of the virus have been deleted to facilitate the accommodation of large gene inserts into the viral genome. 293 calls,human kidney cells transformed with human adenovirus type 5 DNA, express the viral E1 proteins constitutively. As a result, the combination of vectors based on human adenovirus type 5 and 293 cells form an ideal expression system.

A transfer vector, pAdBM5 (Figure 11), was developed in order to insert foreign gene sequences into human adenovirus serotype 5. The vector contains the adenovirus major late promoter (Ad2MLP), enhancer sequences, and polyadenylation sequences, flanked by the adenovirus serotype 5 E1 flanking sequences. A unique BamHI site is located downstream of the MLP and is used for the insertion of foreign genes.

For the expression of either full-length BHV-1 gIV or truncated BHV-1 gIV, the appropriate gene constructs were described above, were digested with BglII and inserted into the dephosphorylated BamHI site of the pAdBM5. Figure 12 depicts pAdBM5.gIV, the adenovirus vector including the gene encoding full-length gIV. The plasmid DNA was digested with ClaI, mixed with purified human adenovirus serotype 5 DNA and was used to transfect 293 cells using the calcium phosphate technique. The transfected cells were plated out and incubated at 37°C until a cytopathic effect developed. Supernatant from these cultures was then removed and used to reinfect 293 cells. Recombinant virions expressing BHV-1 gIV were identified, selected and then further purified by plaque assay.

V.B. Purification of Recombinant Expressed BHV-1 gIV

293 cells were cultured in MEM containing 10% fetal bovine serum and supplemented with 1X vitamins and miner-

als. Confluent monolayers were infected with the recombinant adenovirus expressing BHV-1 gIV at a multiplicity of 0.1. 24 hours after infection or at the appearance of total cytopathic effect, recombinant gIV was harvested.

For full-length gIV, the cells were scraped from the surface of the culture flasks into the growth media, which was then centrifuged (1000 g for 20 min) and the cell pellet collected. The cells were disrupted with detergent and further processed as previously described.

Truncated gIV was collected by harvesting the media from the culture flasks. Cell debris was removed by centrifugation at 1000g for 20 min. The clarified media was frozen at -70°C until processing. The truncated gIV was purified by affinity chromatography through BHV-1 gIV specific columns, as has been described previously.

VI

This example illustrates the efficacy of recombinantly produced BHV-1 subunit antigens.

VI.A. Materials and Methods

VI.A.1. Cells and Viruses

E. coli cells were cultured in L Broth. Madin Darby bovine kidney cells (MDBK) cells, BSC-1 cells, and 293 cells were cultured in Eagle's minimal essential medium (MEM; GIBCO laboratories, Grand Island, N.Y., USA), supplemented with 10% fetal bovine serum (FBS; GIBCO). Spodoptera frugiperda (SF9) cells were grown and maintained in TNM-FH medium (GIBCO) containing 10% FBS. Strains P8-2 and 108 of BHV-1 were propagated in MDBK cells as described previously (Babiuk et al. (1975) Infect.Immun. 12:958). Virus recovered from nasal swabs was quantified by plague titration on MDBK cells in microtiter plates with an antibody overlay as previously described (Rouse et al.(1974) J.Immunol. 113:1391). Vaccinia virus (WR strain) and recombinant vaccinia virus were propagated in BSC-1 cells as described in Example II. Human adenovirus type-5 and recombinant adenovirus were grown in 293 cells as described in Example V. Virus stocks of the baculovirus AcNPV and recombinant virus were prepared in SF9 cells as described by Summers and smith (Summers et al., "A manual of methods for baculovirus vectors and insect cell culture procedures. Texas Agricultural Experiment Station Research bulletin no. 1987, 1555, Texas Agricultural Experiment Station, College Station, Tex).

VI.A.2. Recombinant Expression of gIV

BHV-1 gIV was recombinantly expressed in E. coli, baculovirus, SF9 cells, adenovirus, vaccinia virus and mammalian cells, as explained in the above examples.

VI.A.3. Preparation of Immunoadsorbent Columns

The IgG fraction of the gIV-specific monoclonal antibody 3D1Gb was prepared from ascites fluid, using a protein A-Sepharose CL-4B (Pharmacia, Montreal, Quebec, Canada) column. The purified IgG was dialyzed thoroughly against 0.1 M HEPES, pH 7.5 and linked to activated Affigel-10 (RioRad Laboratories, Mississauga, Ontario, Canada) at 5 mg protein per ml gel according to the manufacturer's instructions. An immunoadsorbent column was packed for each of four different gIV species.

VI.A.4. Purification of Glycoproteins

Glycoprotein gIV was purified from BHV-1 (strain P8-2) infected MDBK cells, recombinant AcNPV infected SF9 cells, recombinant adenovirus infected 293 cello or recombinant vaccinia virus infected BSC-1 cells. Cell lysates were prepared from the virus infected cells, essentially as described previously (Van Drunen Littel-van den Hurk et al. (1985) Virology 144:204-215). Briefly, the cells were harvested, centrifuged at 1000 rpm and resuspended in 10 mM Tris-hydrochloride, 150 mM NaCl, pH 7.5 containing 1% Nonidet P40 (NP40) and 1% sodium deoxycholate. After the cell lysates had cycled three times through the respective gIV-specific monoclonal antibody columns, the columns wer washed with one volume of sample application buffer and two volumes of wash buffer (10 mM Tris-hydrochloride, 500mM Macl, 0.1% NP40, pH 7.5). Specifically bound antigen was eluted with 50 mM diethylamine, pH 11.5, immediately neutralized with 1 M Tris-hydrochloride, pH 7, and concentrated on an Amicon YM30 membrane. The columns were re-equilibrated in sample application buffer for reuse or stored in phosphate-buffered saline (PBS), containing 0.02% sodium azide. The protein content was determined with the BioRad protein determination kit. The purity was assessed by polyacrylamide gel electrophoresis alone and in combination with western blotting. Finally, the purified proteins were applied to appropriate cells to test for residual input virus.

VI.A.5. Polyacrylamide Gel Electrophoresis

Sodium dodecyl sulphate (SDS)-polyacrylamide gel electrophoresis (PAGE) was carried out in 10% discontinuous gels under reducing conditions as described previously (Laemmli, U.K. (1970) Nature 227:680-685).

VI.A.6. Immunization

Groups of eight calves each were immunized intramuscularly with 25 ug of purified gIV, produced by BHV-1, baculovirus, adenovirus or vaccinia virus, or 100 ug of gIV produced in E. coli. The glycoproteins were combined with the adjuvant Avridine as described previously (Babiuk et al. (1987) Virology 159:57-66). A control group was vaccinated with Avridine only. Twenty-one days later the animals were boosted and then challenged with BHV-1 fourteen days after the booster immunization. Blood samples were taken from the animals at the time of the first immunization, booster immunization, and challenge, as well as ten days after challenge for assessment of antibody responses.

VI.A.7. Experimental Challenge

Fourteen days after the second immunization, animals were transported into an isolation pen and examined clinically. Their weights and rectal temperatures were determined and recorded. Blood samples and nasal swabs were collected to establish baseline values. The calves were then individually exposed to an aerosol of 10^7 pfu per ml of BHV-1 strain 108, which was generated by a DeVilbis Nebulizer, model 65 (DeVilbis, Barrie, Ontario, Canada). The duration of the treatment was 4 min per calf.

VI.A.8. Clinical Evaluation

The clinical evaluations were performed at the same time each day by two independent investigators who were uninformed about the specific treatments of the individual animals. The parameters evaluated included depression, appetite, fever, conjunctivitis, rhinitis, mouth-breathing and tracheitis. In each case, a score of 0 was assigned to healthy animals. Clinical scores of 1-4 were assigned to sick animals as follows: 4, severe; 3, marked; 2, moderate; 1, mild. Temperatures were taken every day and nasal swabs were collected every other day and processed the same day. Blood samples were collected ten days after challenge.

VI.A.9. Enzyme-linked Immunosorbent Assay (ELISA)

In order to determine the gIV-specific antibody responses of the calves, the ELISA was performed essentially as previously described (Van Drunen Littel-van den Hurk (1984) Virology 135:466). Polystyrene microtiter plates (Immulon 2, Dynatech Laboratories Inc., Alexandria, VA, USA) were coated with 0.05 ug purified gIV per well and incubated with serially diluted bovine sera. Affinity-purified horseradish peroxidase (HRPO)-conjugated rabbit anti-bovine IgG (Kirkegaard & Perry Laboratories, Gaithersburg, Maryland, USA), at a dilution of 1:5000, was used as the detecting antibody. Antibody isotypes were determined in an indirect ELISA using gIV-coated plates and isotype-specific monoclonal antibodies (provided by Dr. K. Nielsen, Agriculture Canada, Animal Diseases Research Institute, Nepean). Affinity-purified HRPO-conjugated goat anti-mouse IgG (Boehringer-Mannheim, Dorval, Quebec, Canada) at a dilution of 1:10,000 was used as the detecting antibody.

VI.A.10. Competitive Antibody Binding Assay (CBA)

The CBA was based on the ELISA modified as previously described (Van Drunen Littel-van den Hurk et al. (1985) Virology 144:216-227). Briefly, gIV coated plates were incubated with serially diluted competitor antibodies from the gIV-immunized calves. After a 3 hour incubation at 37°C, the plates were washed and incubated with HRPO-conjugated monoclonal antibodies specific for eight different epitopes on gIV (Van Drunen Littel-van den Hurk (1984) Virology 135:466; and Hughes et al. (1988) Arch. Virol. 103:47). After a 1 hour incubation at 37°C, the plates were washed again and developed. The percentage competition was calculated using the formula [100x(A-B)/A] where A is absorbance in absence of competitor antibody and B is absorbance in the presence of competitor monospecific antibody.

VI.A.11. Neutralization Test

The neutralization titers of the bovine sera were determined as described previously (Babiuk, L.A. et al. (1975) Infect. Immun. 12:958). The titers were expressed as the reciprocal of the highest dilution of antibody that caused a 50% reduction of plaques relative to the virus control. Neutralization titers were also determined for the nasal swabs of

the immunized animals and calculated in the same manner.

VI.B. Results

VI.B.1. Purification of Authentic and Recombinant gIV

Authentic and recombinant gIVs were purified on gIV-specific monoclonal antibody columns. All of the recombinant gIV glycoproteins were produced at higher levels than the authentic gIV from BHV-1 (Table 1).

Table 1

Source of gIV	[a]Yield1(ug/10^6 cells)
BHV-1	1 - 2.5
Baculovirus	15 - 35
Adenovirus	3.5 - 8.5
Vaccinia virus	2.5 - 5.5
E. coli	[b]500 - 1000

[a] The yields of gIV from mammalian cells were determined with the BioRad protein determination kit.
[b] The yields of gIV from E. coli are expressed in ug per liter and represent values obtained on bench scale before optimalization.

The purity of the glycoprotein preparations was assessed by SDS-PAGE. All of the recombinant forms of gIV bound specifically to the columns. The apparent molecular weights of authentic gIV and gIV from vaccinia virus and adenovirus were identical, indicating that processing and glycosylation of authentic gIV in MDBK cells and recombinant gIV in BSC-1 or 293 cells are very similar. Recombinant gIV from baculovirus, however, had an apparent molecular weight of 63 kDa, which is lower than that of the 71 kDa authentic form. In addition to the 63 kDa species, four bands of lower apparent molecular weight were observed. These bands were consistently seen both in pure and in crude preparations of gIV from baculovirus. Recombinant gIV from E. coli had an apparent molecular weight of 54 kDa, which corresponds to the molecular weight of the unglycosylated form of gIV (Van Drunen Littel-van den Hurk (1986) Virology 59:401-410). As about 50% of the total protein preparation from E. coli consisted of gIV, this recombinant protein was not further purified. The gIV from E. coli was not dimerized at all, whereas the gIV from baculovirus showed a much reduced degree of dimerization as compared to authentic gIV.

VI.B.2. Immune Responses to Authentic and Recombinant gIV

In order to determine whether the different forms of recombinant gIV have the name protective capacity as authentic gIV, they were evaluated in a BHV-1 challenge experiment a described above. The level and the specificity of the total antibody response following immunization was determined in an ELISA using authentic gIV, gI or gIII as the antigens. After one immunization, high levels off gIV-specific antibodies were found in the sera of all immunized animals. The antibody titers increased following the booster immunization. There was no significant difference between the antibody titers induced by gIV from BHV-1, baculovirus, adenovirus or vaccinia virus. However, the antibody titers generated by gIV from E. coli were 5-fold higher after the booster Immunization. None of the animals reacted with gI or gIII, showing the specificity of the immune response. In no case did the placebo-vaccinated animals produce any immune response.

In order to predict the effectiveness of the glycoprotein-specific antibodies to prevent infection, the serum neutralizing antibody titers were determined. After one immunization, gIV from BHV-1, baculovirus, adenovirus and vaccinia virus induced reasonably good levels of neutralizing antibodies, which increased to very high levels following the booster immunization. Again, there was essentially no difference between the immune responses to these four forms of gIV. In contrast, there was a significant difference in the neutralizing antibody response to gIV from E. coli. Even after two immunizations, the neutralizing antibody titer induced by this form of gIV was lover than the level induced by one immunization of any of the other forms of gIV.

The contribution of antibody isotypes to the immune response was investigated by indirect ELISA. The IgG1 titers

were higher than the IgG2 titers throughout the period before challenge. The IgG1 titers reached pea values after two immunizations and then started to plateau and decrease after challenge. The IgG2 titers were lower initially, but generally continued to increase after challenge. The IgM titers were much lower than the IgG1 or IgG2 titers throughout the duration of the experiment. The antibody isotypes were generally similar between the groups immunized with the different forms of recombinant gIV. However, the IgM levels induced by gIV from E. coli were significantly higher than those induced by the other forms of gIV. The IgG1 response, however, wag slower in this group.

VI.B.3. Epitope Specificity of the Immune Response to Authentic and Recombinant gIV

Recombinant gIV from E. coli induced a lower level of neutralizing antibodies to BHV-1 than the other recombinant gIVs, although the total antibody response was equivalent or higher. In order to determine which of the neutralizing epitopes on gIV were recognized, the sera from all immunized animals were tested with respect to epitope specificity. Seven neutralizing epitopes (epitopes Ia, Ib, II, IIIa, IIIb, IIIc, and IIId) and one non-neutralizing epitope (epitope IV) have been mapped on gIV (Hughes et al. (1988) Arch. Virol. 103:47). All epitopes on gIV were recognized by animals immunized with gIV from BHV-1, baculovirus, adenovirus, or vaccinia virus; blocking varied between 30 and 95%, depending on the epitope. These values correlate well with previously reported values between 30 and 85% (Van Drunen Littel-van den Hurk (1990) Vaccine 8:358-368). However, the neutralizing epitopes on gIV were either not at all (Ia, Ib, II, IIIa, and IIIb), or poorly (IIIc and IIId) recognized by animals immunized with gIV from E. coli. The only epitope recognized well by these animals was the non-neutralizing epitope IV. These results indicate that the neutralizing epitopes on gIV, most or which are conformation-dependent (Hughes et al. (1988) Arch. Virol. 103:47), are present on gIV from baculovirus, adenovirus and vaccinia virus, but not on gIV from E. coli.

VI.B.4. Protection from Challenge with BHV-1

All animals were challenged with an aerosol of BHV-1. Prior to challenge, all animals were healthy and they had a normal rectal temperature. However, within 24 h post infection, the animals in the placebo-immunized group started to exhibit a sharp rise in temperature. The temperatures continued to increase until three days post challenge, whereafter they declined again. There was no significant increase in temperature in the gIV-vaccinated groups, although the animals immunized with gIV from E. coli did experience some elevated temperatures during the first two days after infection. In addition to the temperature responses the calves were clinically evaluated for signs of respiratory disease. The clinical illness scores correlated well with the temperature responses. The animals in the placebo-immunized group showed signs of clinical illness from day 1 until day 7 post challenge, whereas the groups immunized with gIV from BHV-1, baculovirus, adenovirus or vaccinia virus experienced no illness at all. The group that received gIV from E. coli showed mild disease for three days after infection. A further non-subjective assessment of morbidity is the extent of weight loss of animals challenged with BHV-1. The weight loss observed in the placebo-immunized group is a reflection of the anorexia as a result of the morbidity due to viral challenge. In contrast to the placebo-immunized group, gIV immunized animals experienced minimal or no weight loss during the 8 days following challenge.

VI.B.5. Induction of Mucosal Immunity

With the exception of the group immunized with gIV from E. coli, all animals vaccinated with authentic or recombinant gIV were fully protected from disease, when challenged with BHV-1. To determine whether they were also protected from viral infection, the extent of virus shedding from the nasal passages was assessed. Essentially no virus was recovered from the nasal swabs of animals vaccinated with gIV from BHV-1, baculovirus, adenovirus or vaccinia virus. One animal in each of the groups vaccinated with gIV from baculovirus and adenovirus shed virus for one day. In contrast, all animals immunized with gIV from E. coli or placebo shed virus for 7 to 9 days post challenge. These data indicated that intramuscular immunization with a subunit vaccine induced mucosal immunity in the nasal passages, thereby preventing viral infection. In addition, the extent of the mucosal immunity appeared to correlate with the level of the neutralizing antibodies in the serum. To confirm the presence of a mucosal immune response in the nasal passages, the antibody titers in the nasal swabs were determined. On the challenge day, groups vaccinated with gIV from BHV-1, baculovirus, adenovirus, or vaccinia virus had mean neutralizing antibody titers between 25 and 65. The gIV-specific ELISA titers correlated wall with the neutralizing antibody titers. The group immunized with gIV from E. coli did not have any neutralizing antibodies in the nasal secretions, although the total gIV-specific antibody levels were as high as in the other groups. No gI-or gIII-specific antibodies were found in the nasal secretions (data not shown). These data correlate well with the serum antibody levels.

VII

This example illustrates the production of a BHV-1 gI by recombinant baculovirus vectors.

VII.A. Materials and methods

VII.A.1. Cells, viruses and antibodies - Madin Derby bovine kidney (MDBK) cells were cultured in Eagle's minimal essential medium (Grand Island Biological Co., Grand Island, N.Y.) supplemented with 10% fetal bovine seruma (FBS) (Gibco). Virus stocks of BHV-1 strain Cooper were grown in MDBK cells as previously described (Babiuk et al., 1975 Infect. Immun. 12:958-963). Spodoptera frugiperda (SF9) cells were grown and maintained in TNM-FH medium (GIBCO) containing 10% FBS according to the procedures described by Summers and Smith (1987 Texas Agricultural Experimental Station Bulletin No. 1555, College Station, TX). Virus stocks of wild-type AcNPV and recombinant virus were prepared in SF9 cells as described by Summers and Smith (1987 supra). Monoclonal antibodies specific for gI were developed and characterized by van Drunen Littel-van den Hurk et al. (1984 Virology 135:466-479). The gI-specific monoclonal antibody mixture used for identification of recombinant gI consisted of equivalent counts of 1B10 (epitope I), 3F3 (epitope II), 1E11 (epitope III), 1F8 (epitope IVa), 5G2 (epitope IVb), 3G11 (epitope IVb), 5G11 (epitope IVc), 6G11 (epitope IVc), 1F10 (epitope V) and 2C5 (epitope V).

VII.A.2. Insertion of BHV-1 gI DNA into the transfer vector - A cassette of the gI glycoprotein gene has been prepared in plasmid psV2Neo as previously described (Fitzpatrick et al., (1988), J. Virol., 62:4239-4248. The plasmid was digested with restriction endonuclease BgIII and the fragment representing the gI gene was purified by agarose gel electrophoresis and ligated into the BamHI site of baculovirus transfer vector pVL941. After transformation of E. coli strain JM105, colonies appearing on L agar containing 100 μg/ml ampicillin were inoculated to L broth containing ampicillin and incubated at 37°C overnight with vigorous shaking. Small scale preparations of plasmid from each colony wore prepared and the presence of the gI gene was confirmed by digestion with endonucleases AvaI and EcoRV. A single clone was identified containing the gI gene in the desired orientation and designated pVIgB. Clone pVIgB wan inoculated into 500 ml L broth containing ampicillin and after 24 h at 37°C, plasmid was prepared by alkaline lysis and further purified by equilibrium centriguation on CsCl.

VII.A.3. Transfection and selection of recombinant viruses - After two cycles of ethanol precipitation, purified plasmid was mixed with an equal amount of A. californica viral DNA and used to transfect subconfluent monolayers of SF9 cells as outlined by Summers and Smith (1987) supra. Recombinant baculoviruses were identified by plaque hybridization essentially as outlined by summers and smith (1987) supra. The polyhedrin-negative recombinants were plaque-purified 3 to 4 times on SF9 cells to remove contaminating wild-type baculovirus

VII.A.4. Preparation of cell lysates - To analyze expression of recombinant gI, confluent monolayers of SF9 cells on 35 mm petri dishes were infected with individual polyhedrin-negative recombinants at a moi of 5 and incubated for 48 h at 28°C. The cells ware scraped into PBS, pelleted at 150xg for 1 min, and resuspended in 50 μl of RIPA buffer (0.02 M Tris-hydrochloride [pH 8.0], 0.15M NaCl, 1% 10 mM phenylmethylsulfonylfluoride [PMSF]). The postnuclear supernatant was collected and 5 μl was combined with reducing electrophoresis sample buffer and boiled for 2 min for analysis by SDS-PAGE and immunoblotting. To determine approximate yields of recombinant gI, SF9 calls in monolayers or suspension cultures were infected with recombinant virus at a moi of 1. The cells wore harvested at various times post infection, washed with PBS and resuspended in RIPA buffer at $1x10^7$ cells/ml for analysis by ELISA. Equivalent samples from uninfected cells and/or cells infected with the parental virus were always included as controls.

VII.A.5 Analysis of carbohydrates - Proteins were digested with endoglycosidase H or glycopeptidase F as described by Ronin et al. (1987), Biochemistry, 26:5848-5853. Infected cells were collected by centrifugation and $2x10^5$ cells were resuspended in 10 μl of appropriate enzyme incubation buffer. Digestion with glycopeptidase F (Boehringer-Mannheim, Laval, Quebec, Canada) was performed in 50 mM Trishydrochloride (pH 8.6), 25 mM EDTA, 1% Triton X100, 1% 2-mercaptoethanol, 0.2% SDS and 1.5 U of enzyme. Digestion with endo H (Boehringer-Mannneim) was performed in 0.1 M sodium acetate (pH 5), 0.15 M sodium chloride, 1% Triton X100, 1%- 2-mercaptoethanol, 0.2% SDS, and 1.5 mU of enzyme. The cells wore incubated for 18 h at 37°C. Proteins were precipitated by adding 1 ml of ice-cold acetone and centrifugation. They were subjected to SDS-PAGE followed by immunoblot analysis. Tunicamycin was added to recombinant AcNPV-infected SF9 calls or BHV-1 infected MDDBK cells at the time of infection from a stock solution of 1 mg/ml in ethanol. SF9 cells were harvested at 48 h post infection and MDBK cells were harvested at 24 h post infection.

VII.A.6 SDS-PAGE, Immunoblot and ELISA - Sodium dodecylsulfate-polyacrylamide gel electrophoresis (SDS-PAGE) was performed in 8.5% or 10% polyacrylamide discontinuous gels as previously described (van Drunen Littel-van den Hurk et al., 1984), supra. Electrophoresis was carried out under reducing conditions. Protein bands were visualized by staining with coomassie brilliant blue. In order to identify recombinant gI, produced by baculovirus, an immunoblot assay was performed as previously described (van Drunen Littel-van den Hurk et al., 1984), supra. Briefly, after electrophoresis, cell lysates were elcctrophoretically transferred to nitrocellulose sheets. Subsequently, the instructions for use of the Bio-Rad (Mississauga, Ontario) immunoblot assay kit were followed. One gI-positive recombinant baculovi-

rus, named Bac-gI, was amplified by growth on SF9 cells. The supernatants from this infection were stored at 4°C and used in all subsequent experiments.

Sandwich and indirect ELISA's were used to determine the yields of glycoprotein gI in recombinant baculovirus-infected SF9 cells. In the sandwich assay, microtiter plates were coated with the IgG fraction of bovine hyperimmune serum as the capture antibody and then incubated with lysates from recombinant virus - infected and control cells, or affinity-purified standard gI. In the indirect assay, the cell lysates and glycoproteins were directly adsorbed to the microtiter plates. Mixtures of gI-specific monoclonal antibodies, followed by horseradish peroxidase (HRPO)-conjugated goat anti-mouse IgG (Boehringer-Mannheim) were used for detection as previously described (van Drunen Littel-van den Hurk et al., 1984) supra). The reaction was visualized using 0.8 mg/ml of 5-aminosalicylic acid and 0.006% H_2O_2, as described.

VII.A.7. Immunofluorescence and flow cytometry - The expression of glycoprotein gI in recombinant baculovirus-infected SF9 cells was determined at 24, 48 and 72 h post infection. Briefly, cells were washed in PBS and cytospin smears were prepared and fixed in methanol. They were incubated for 30 min at 37°C with a 1:100 dilution of a gI-specific monoclonal antibody mixture and washed in PBS and ddH_2O. They were stained with fluorescein isothiocyanate-conjugated (FITC) rabbit anti-mouse IgG (Boehringer-Mannheim) for 30 min at 37°C and washed again before being mounted in PBS-glycerol for examination. For surface staining and flow-cytometric analysis, cells were suspended in PBS containing 0.2% gelatin and 0.03% NaN_3 (PBSG) at $4x10^7$ cells/ml. They were plated in microtiter plates at $2x10^6$ cells per well and incubated with serial dilutions of monoclonal antibody mixtures for 30 min on ice. Subsequently, they were washed in PBSG and then incubated with FITC rabbit anti-mouse IgG for 30 min at 4°C. After washing, the cells were fixed in 2% formaldehyde and analyzed with an EPICS CS (Coulter Electronics Ltd.) flow cytometer as described elsewhere (Campos et al. (1989), Cell. Immunol., 120:259-269. The percentage of positive cells was calculated using the immuno-program (Coulter Electronics Ltd., MDAPs system) for the analysis of immunofluorescence histograms.

VII.A.8. Cell fusion assay - Monolayers of SF9 cells in 24-well tissue culture plates were infected with recombinant virus at a moi of 5-10 PFU per cell. At 36 h post infection, the medium was replaced with TNM-FH medium, adjusted to a pH ranging from 5.0 to 6.5 Syncytia formation was monitored under a phase contrast microscope (Zeiss Model IM35; magnification 200x). Monospecific and monoclonal antibodies were added at a dilution of 1:100 at the time of pH shift.

VII.A.9. Immunization of cattle - Glycoprotein gI was purified by immunoadsorbant chromatography from Bac-gI infected SF9 cells or BHV-1 infected MDBK cells as described in detail previously (van Drunen-Littel van den Hurk and Babiuk (1985), Virology, 144:204-215. Groups of eight animals each were immunized with 10 µg of affinity-purified recombinant or authentic gI in Emulsigen™ PLUS at a ratio of 7:3 (vol/vol) as outlined by the manufacturer (MVP Laboratories, Ralston, Ne.). The animals were injected intramuscularly and they received a booster immunization 28 days later. They were bled at the times of immunization and two weeks after the second immunization for assessment of antibody responses. The antibody response to gI in the vaccinated animals was assayed in an immunoblot assay with purified BHV-1 as the antigen, as described previously (van Drunen Littel-van den Hurk et al. (1990), Vaccine, 8:358-368.

VII.B Results

VII.B.1 Production of recombinant gI glycoprotein in SF9 cells - Recombinants containing the gI gene inserts were tested for their ability to produce BHV-1 glycoprotein I after infection of SF9 cells. All of the gI recombinants directed the synthesis of a polypeptide with an apparent molecular weight of 116 kDa, which was visible on a coomassie brilliant blue stained gel at 48h post infection. This protein was missing in uninfected cells and cells infected with the parental baculovirus. In order to confirm the identify of this glycoprotein, immunoblot analyses were performed on Bac-gI infected SF9 cells and BHV-1 inPected MDBK cells. A gI-specific monoclonal antibody mixture that recognized the 130k, 74k and 55k components of authentic gI in BHV-1 infected MDBK cells, reacted with three polypeptides with apparent molecular weights of 116 kDa, 63 kDa, and 52 kDa in Bac-gI infected SF9 cells. This indicates that terminal glycosylation of gI has not occurred in the recombinant virus-infected SF9 cells. Recombinant gI was cleaved in infected SF9 cells, but not with the same efficiency as authentic gI. No reaction was observed between the gI-specific monoclonal antibodies and SF9 cells infected with the parental baculovirus.

VII.B.2. Processing of gI in mammalian and insect cells - To further analyze the observed difference in molecular weight of the recombinant and authentic gI, Bac-gI infected SF9 cells and BHV-1 infected MDBK cells were treated with tunicamycin, an inhibitor of N-linked glycosylation. In these cells only one polypeptide with an apparent molecular weight of 105k was observed, which corresponds to the previously identified polypeptide backbone of authentic gI (van Drunen Littel-van den Hurk and Babiuk, (1986) J. Virol., 59; 401-410. This experiment proved that the reduced molecular weight of gI expressed in insect cells was due to incomplete glycosylation. To compare the type of carbohydrate attached to recombinant and authentic gIV, both glyco-proteins were subjected to digestion with endo H or endo F. Digestion with endo H resulted in a slight decrease in apparent molecular weight or authentic gIa and gIc, but had no effect on gIb, which confirms previous studies (van Drunen Littel-van den Hurk et al., (1986) supra. The greater portion of recombinant gIa and gIc was sensitive to endo H, showing the presence of high-mannose type oligosaccharides. However,

the recombinant glb was not sensitive to endo H, indicating that those oligosaccharides are trimmed. All of the recombinant and authentic forms of gI wore endo F sensitive, showing precursor molecules with similar apparent molecular weights in BHV-1 and Bac-gI infected cells.

Authentic and recombinant gI are both cleaved during processing to the mature polypeptide. However, the cleavage process is incomplete in mammalian cells and even less efficient in insect cell. It has been proposed that Arg-Arg-Ala-Arg-Arg sequence (501-505), which occurs in the region of non-similarity with HSV-1, may be the processing site for PRV gII (Robbins et al., (1987) J. Virol., 61:2691-2701 and BHV-1 gI (Whitbeck et al., (1988) J. Virol., 62:3319-3327. To confirm the position of the cleavage site of authentic as well as recombinant gI, we sequenced the N-terminus of the glc glycoprotein from infected MDBK and SF9 cells. This analysis confirmed that the first 12 N-terminal amino acids of authentic and recombinant glc correspond to positions 506-517. Since recombinant gI was cleaved at the same site as authentic gI, the reduced cleavage efficiency is probably due to the presence of relatively low amounts of enzyme in baculovirus-infected cells, as compared to the large amounts of gI produced in these cells. N-terminal sequencing of the glb glycoprotein demonstrated that the signal is cleaved in MDBK and SF9 cells and that the amino terminal residue of authentic as well as recombinant gI is Arg-68.

VII.B.3 Kinetics and level of expression of the recombinant gI glycoprotein - The amount of gI synthesized in recombinant baculovirus-infected SF9 cells was quantitated by ELISA, standardized with affinity-purified recombinant gI. SF9 cello grown as monolayers in 35 mm petri dishes were infected with Bac-gI at a moi of 5, and aliquots of $1x10^6$ cello were harvested at various times post infection. Cell lysates were prepared and the level of expression of recombinant gI was tested in the ELISA. Immunoreactive gI could be detected as early as 24 h after infection and maximal expression was observed between 36 and 48 h, whereafter a slight decrease in measurable glycoprotein occurred. This decline presumably reflected cell lysis and sub-sequent degradation of the glycoprotein. This analysis showed that, at maximal levels of expression, 30 μg of gI were produced per 10^6 cells. In order to analyze the possibility to produce recombinant gI at a larger scale, SF9 cells were grown in suspension cultures and infected with the recombinant baculovirus at a moi of 1. In addition to yield by ELISA, the viability of the cells and percentage of infected cells were determined. Flow cytometric analysis showed an increase in percentage of infected cells (y-axis) as well as total protein yield (x-axis) over time. The percentage of infected cells increased gradually, reaching peak levels of 85% at 72 h after infection, when the viability of the cells was down to 25%. The viability of the cells was too low for flow cytometric analysis beyond this time point. Analysis by ELISA demonstrated that up to 35 μg of gI were produced per 10^6 cells. This demonstrated the feasibility of growing the recombinant baculovirus on a larger scale and yet obtain good yields of the glycoprotein.

VII.B.4 Intracellular localization of recombinant gI in SF9 cells - The intracellular distribution of the recombinant gI glycoprotein was examined by an indirect immunofluorescence assay. At 48 h post infection, recombinant gI was primarily localized in the perinuclear membranes of the infected SF9 cells. To determine whether the recombinant gI was present on the surface of infected cells, immunofluorescence analysis was carried out on unfixed cells. Localization of gI was demonstrated by bright fluorescences on the surface. Wild-type AcNPV-infected control cells did not show any fluorescence with the gI-specific monoclonal antibody panel (not shown).

VII.B.5. Fusogenic properties of recombinant gI in insect cells - It has been shown previously that one of the functional characteristics of gI is its ability to induce cell fusion in absence of other viral proteins (Fitzpatrick et al., (1988) supra; (1990) J. Gen. Virol., 71:1215-1219. To determine whether this functional property was retained in the recombinant protein, SF9 cells were infected with Bac-gI. Fusion of the insect cells was not evident under standard culture conditions, but after a shift to pH 5.4, fusion was apparent in Bac-gI infected SF9 cells within two hours. The syncytia formation observed in these cells continued to increase over 8 h of observation. Inclusion of gI-specific rabbit serum or a mixture of gI-specific monoclonal antibodies completely inhibited fusion by gI as set forth in Table 2.

Table 2

Inhibition of fusion activity mediated by gI expressed in baculovirus	
Treatment[a]	Fusion activity (%)[b]
TNM-FH, pH 5.4	80
Trypsin	80
Normal Rabs	80
gI-specific Rabs	0
Control Mabs	80
gI-specific Mabs mixture	0
1B10 mab (I)	5
3F3 Mab (II)	80
1E11 Mab (III)	80
1F8 Mab (IVa)	80
5G2 Mab (IVb)	10
5G11 Mab (IVc)	60
1F10 Mab (V)	80

a. Cell fusion was induced at 36h post infection by replacing the cell culture medium with TNM-FH pH 5.4. At the time of pH shift a final dilution of 1:100 of Rabs (rabbit serum) or Mabs (monoclonal antibodies) was added to the medium. Treatment with 20 µg trypsin was carried out for 10 min, just before pH shift at 36h.
b The cells were counted 8h after the pH shift. The percentage of fused cells was calculated on a total of 400 cells and rounded to the nearest decimal.

When individual monoclonal antibodies were included in the media, fusion was almost completely inhibited by the monoclonal antibodies 1B10 (epitope I) and 5G2 (epitope IVb) and partially inhibited by 5G11 (epitope IVc). Inclusion of trypsin at the time of pH shift did not affect the fusion activity.

VII.B.6. Antigenic and Immunogenic properties of gI expressed in SF9 cells - The antigenic properties of recombinant gI were evaluated using a panel of gI-specific monoclonal antibodies. The epitopes recognized by these monoclonal antibodies have been identified and characterized previously (van Drunen Littel-van den Hurk et al. (1985) supra; Fitzpatrick et al. (1990) Virology, 176:145-157. Reactivity of all of these monoclonal antibodies in an ELISA (Table 3b) indicated that all of the epitopes identified on the authentic glycoprotein were also present on the recombinant gI glycoprotein.

The reaction between the monoclonal antibodies and two carbohydrate-dependent epitopes IVa and IVc; (van Drunen Littel-van den Hurk et al., 1990b) was weaker on recombinant gI than on authentic gI, which is in agreement with lack of terminal glycosylation of gI in Sf9 cells. Epitopes I, II, and III, however, appeared to be more reactive on recombinant gI than on its authentic counterpart.

To compare the immunogenicity of recombinant and authentic gI, calves were immunized with affinity-purified glycoprotein from recombinant Bac-gI-infected Sf9 cells or BHV-1 infected MDBK cells. Two immunizations of recombinant or authentic gI in Emulsigen PLUS elicited antibodies that were reactive with gI from BHV-1 in an immunoblot assay. The antibody titers induced by recombinant and authentic gI were very similar (Table 3a).

Table 3a

Immune Response to Authentic and Recombinant gI		
Immunogen[a]	Dose (µg)	Antibody titer[b]
Authentic gI	100	8,125
Authentic gI	10	2,580
Recombinant gI	100	10,240
Recombinant gI	10	1,280
Placebo	N.A.	10

[a] Animals received two intramuscular immunizations of authentic gI, recombinant gI, or PBS (placebo) in Emulsigen PLUS.

[b] ELISA titers were determined against affinity-purified gI and expressed as the reciprocal of the highest dilution resulting in a reading of two standard deviations above the negative control value.

Table 3b

			ELISA Titer[d]	
Monoclone Designation[a]	Epitope Specificity[b]	Neutralizing Activity[c]	BHV-1 gI	AcNPV gI
1B10	I	-	100	6400
3F3	II	+/-	6400	25600
1E11	III	++	1600	6400
IF8	IVa	+	25600	6400
5G2	IVb	+	6400	6400
3G11	IVb	+	1600	1600
5G11	IVc	+	1600	100
6G11	IVc	++	400	100
1F10	V	+/-	1600	1600
2C5	V	+/-	6400	6400

a. Monoclonal antibodies developed by van Drunen Littel et al. (1984)

b. gI epitopes assigned by competitive binding assays (van Drunen Littel-van den Hurk al., 1985).

c. Neutralizing titers were determined for ascites fluids in the presence of guinea pig serum as a source of complement. -, titer < 4; +/-, titer<100; +, titer > 100; ++; titer > 10,000. (Van Drunen Littel-van den Hurk et al., (1985) supra.

d. Antigen titer was expressed as the reciprocal of the highest dilution of infected cells giving a reading of at least 0.05 OD (492nm). A 1:100 dilution corresponds to $2x10^4$ cells.

The reaction between the monoclonal antibodies and two carbohydrate-dependent epitopes (IVa and IVc; van Drunen Littel-van den Hurk et al. (1990) J. Gen. Virol., 71:2053-2063) was weaker on recombinant gI than on authentic gI, which is in agreement with lack of terminal glycosylation of gI in SF9 cells. Epitopes I, II and III, however, appeared to be more reactive on recombinant gI than on its authentic counterpart.

To study the immunogenicity of recombinant gI, cattle were immunized with 10 µg of affinity-purified glycoprotein from recombinant baculovirus-infected SF9 cells. Two immunizations of recombinant gI in Emulsigen elicited antibodies that were reactive with gI from BHV-1 in an immunoblot assay.

VIII

Construction of Recombinant AcMNPV Expressing Secreted BHV-1 gIV.

VIII.A. Standard protocols , described in "A Manual of Methods for Baculovirus Vectors and Insect Cell Culture Procedures" by Summers and Smith were used to generate the above recombinant. We used the gene replacement vector, pAcYM1 (see Ann. Rev. Microbiol. 42:177), to direct the insertion of the modified gIV gene(see below) into the polyhedron gene locus of AcMNPV. Therefore, gIV gene expression was directed by the polyhedron gene promoter and the recombinant virus displayed a polyhedron negative phenotype.

The following procedures were used to generate the insertion plasmid required to produce a baculovirus capable of secreting gIV from infected cells. The entire gIV gene coding sequence is contained within a single 1303 bp Mae I fragment (see gIV gene sequence Figure 1 + restriction endonuclease map, Figure 15). A Mac I site exists approx. 45 bp upstream of the gene's initiation codon and approx. 10 bp downstream of the stop codon. This Mae I subfragment was isolated from the BHV-1 HindIII K fragment and treated with T4 DNA polymerase to blunt the ends. The modified fragment was then inserted into the Bgl II site (also treated with T4 DNA polymerase) of a cloning vector. This procedure regenerated the Bgl II cloning sites, such that the gIV gene's coding sequence was now flanked by unique Bgl II sites. In order to make a construct that will permit gIV glycoprotein secretion, the Bgl II modified plasmid was first partially digested with Sac II and a TAB linker (TCGAGC) was added to create a unique Xho I site at the C-terminal Sac II site (located at 1115 bp in the accompanying gIV gene sequence). The C-terminal Sac II site in located at the very 5' terminus of the sequence which encodes the gIV transmembrane sequence. The new plasmid was then digested with Xho I, blunt-end repaired with T4 DNA polymerase followed by insertion of a triphasic translation stop codon linker (CTAGCTAGCTAG) which causes premature translation termination at the 5' terminus of the gIV gene's anchor sequence. The modified gIV gene construct was excised by Bgl II digestion and then inserted into the Bam HI cloning site of pAcYM1. Proper orientation of the gIV gene was established by mapping asymmetric restriction endonuclease sites within the insert relative to unique restriction endonuclease sites in the pAcYM1 backbone. This final construct was used to co-transfect SF9 cells along with purified wild-type genomic AcMNPV DNA by the prescribed procedures of Smith and Summers. (Summers et al., "A manual of methods for baculovirus vectors ad insect cell culture procedures", Texas Agricultural Experiment Station Research bulletin no. 1987, 1555, Texas Agricultural Experiment Station, College Station, Tex.)

VIII.B. Individual polyhedron negative plaques were isolated (see plaque purification procedures), amplified by growth on SF9 calls and tested for expression of secreted gIV by western analysis of serum-free growth media (Ex-Cell 400, JR Scientific) collected from virus infected cells (moi 1.0) 48h post infection. Our analyses demonstrated that approximately 70% of the total gIV produced by this virus was secreted into the media.

VIII.C. Groups of six animals were immunized intramuscularly at a 3 week interval with 25 µg of crude truncated gIV produced from baculovirus-infected Sf9 cells. The tgIV was combined with the adjuvant Avridine as described previously (Babiuk et al, 1987). A control group was vaccinated with Avridine only. Twenty-one days later the animals were boosted and then challenged with BHV-1 fourteen days after the booster immunization. Blood samples were taken from the animals at the time of the first immunization, booster immunization and challenge, as well as ten days after challenge for assessment of antibody responses. One immunization with truncated gIV did not induce detectable levels of serum neutralizing antibodies to BHV-1. However, following the booster immunization good titers of serum neutralizing antibodies were observed in all vaccinated animals (Table 4). After challenge with BHV-1, the animals in the placebo-immunized groups showed signs of clinical illness from day 1 until day 7 post infection (Figure 17a), whereas the group immunized with truncated gIV experienced very little illness. All animals in the placebo group shed high titers of virus for at least 10 days, whereas in the vaccinated group only one animal shed very low levels of virus for 5 days (Figure 17b).

Results of these immunization experiments are shown in Table 4 below and in Figures 17(a) and 17(b).

Table 4

SERUM NEUTRALIZATION TITERS: MEAN + RANGE				
Group	Immunogen[a]	Serum Neutralizing Titer[b] on:		
		1st	2nd	3rd
1	Placebo	<2	<2	<2
2	Crude tIV	<2	<2 (<2-3)	134 (40-640)

[a] Groups of 6 animals were immunized twice at a 3-week interval, with 25 μg of crude truncated IV from baculovirus in Avridine.
[b] Geometric mean serum neutralizing antibody titers and ranges in parenthesis. Where no range is shown, all animals had the same titer: <2.

IX

IX.A.1. Cells and viruses

Madin-Darby bovine kidney (MDBK) cells, BSC-1 cells and human thymidine kinase negative (TK$^-$) 143 cells ware grown as monolayers in Eagle's minimum essential medium (MEM) (GIBCO/BRL, Mississauga, Ontario, Canada), supplemented with 5% fetal bovine serum (FBS) (GIGCO/BRL, Mississauga, Ontario, Canada). LMTK$^-$ cells were grown in Dulbecco's minimum essential medium (DMEM) (GIBCO/BRL, Mississauga, Ontario, Canada) supplemented with 5% FBS. The P8-2 strain of BHV-1 was propagated in MDBK cells and quantitated as described in Rouse et al. (1974) J. Immunol., 113:1391-1398). Wild type (WR strain) and recombinant VVs were propagated in BSC-1 cells and LMTK$^-$ cells (Mackett et al. (1984) J. Gen. Virol., 49:857-864).

IX.A.2. Construction of recombinant plasmids

Restriction endonucleases, and other DNA modifying enzymes were purchased from Pharmacia (Dorval, Quebec, Canada) and New England Biolabs (Mississauga, Ontario, Canada), and were used as directed by the manufacturer.

Construction of the RSV1.3 and RSV1.3X plasmid: The full-length gIV gene was excised from plasmid pRSDneogIV (Tikoo et al. (1990) J. Virol., 64:5132-5142) as a 1.3 kilobase (kb) BglII fragment and inserted into BglII digested pRSV-0 (Fitzpatrick et al. (1988) J. Virol., 62:4239-4248) creating the pRSV1.3 plasmid. This plasmid was partially digested with SacII and a TAB linker (pTCGAGC) was added (Barany, F., (1985) Proc. Natl. Acad. Sci. USA 82:4202-4206) to create a unique XhoI site at the C-terminal SacII site. This plasmid was called pRSV1.3X. All subsequent deletions and truncations were constructed beginning with either of these two plasmids.

a) Plasmid pSTgIV: The gIV gene was subcloned from plasmid pRSDneogIV (Tikoo et al. (1990) supra) as a 1.3 kb BglII fragment, treated with T4 DNA polymerase and ligated to SmaI digested pGS20 (Mackett et al. (1984) supra).

b) Plasmid pSTgIVd1: Plasmid pRSV1.3X was digested with XhoI, blunt-end repaired with T4 DNA polymerase, followed by insertion of a triphasic stop codon NheI Linder (pCTAGCTAGCTAG). The DNA was then digested with NheI and religated. The truncated gIV gene was inserted into the SmaI site of pGS20 as a blunt-end repaired BglII fragment.

c) Plasmids pSTgIVd2 and pSTgIVd5: Plasmid pRSV1.3 was partially digested with NarI and a triphasic stop codon HpaI linker (pd[TTAAGTTAACTTAA]) was inserted after treating the NarI digested plasmid with T4 DNA polymerase. The DNA was finally digested with HpaI and religated. The insertion of the linker at one of the two NarI sites in the gIV gene was confirmed by restriction endonuclease mapping. These two truncations were cloned separately into the SmaI site of pGS20 as a blunt end repaired BglII fragment, creating plasmid pSTgIVd2 (HpaI linker insertion at 3' NarI site) and plasmid pSTgIVd5 (HpaI linker insertion at 5' NarI site).

d) Plasmid pSTgIVd3: Plasmid pRSV1.3 was partially digested with SalI, blunt-end repaired with T4 DNA polymerase followed by ligation with a triphasic stop codon NheI linker (pCTAGCTAGCTAG). The DNA was digested with NheI and religated. The truncated gene was inserted into the SmaI site of pGS20 as a blunt-end repaired BglII fragment.

e) Plasmid pSTgIVd4: Plasmid pRSV1.3 was digested with SmaI, the large fragment purified and then ligated with

a triphasic stop codon NheI linker (pCTAGCTAGCTAG). The DNA was digested with NheI and religated. The truncated gene was inserted into the SmaI site of pGS20 as a blunt-end repaired BglII fragment.

f) Plasmid pSTgIVd6: Plasmid pRSV1.3X was digested to completion with DraIII and XhoI. The large fragment was purified, blunt-end repaired with T4 DNA polymerase and ligated. The partial gene deletion was inserted into the SmaI site of pGS20 as a blunt-end repaired BglII fragment.

g) Plasmid pSTgIVd7: Plasmid pRSV1.3 was digested to completion with SalI and the large fragment was purified and religated. The partial gene deletion was inserted into the SmaI site of pGS10 as a blunt-end repaired BglII fragment.

h) Plasmid pSTgIVd8: Plasmid pRSV1.3X was digested with XhoI and treated with mung bean nuclease to create blunt ends. Then DNA was partially digested with XmaI, treated with Klenow enzyme and the large fragment was then purified and religated. The partial gene deletion was inserted into the SmaI site of pGS20 as a blunt-end repaired BglII fragment.

i) Plasmid pSTgIVd9: Plasmid pRSV1.3 was partially digested with SalI followed by complete digestion with XhoI. The large fragment was purified, blunt-end repaired and then religated. The partial gene deletion was inserted into the SmaI site of pGS20 as a blunt-end repaired BglI fragment.

IX.A.3. Isolation of recombinant vaccinia viruses

The desired recombinant VVs were made by homologous recombination as previously described (Mackett et al. (1985) "DNA cloning: A Practical Approach," pp. 191-211, Ed. by D.M. Clover, Oxford: IRL press). A newly confluent monolayer (75 cm^2) of BSC-1 cells was infected with wild-type VV (WR strain) at a multiplicity of infection of 0.05 PFU/cell. At 4 hrs post infection the cells were collected by mild trypsinization, washed three times with Hepes buffer (pH 7.1) and adjusted to a concentration of 1-2X10^6 cells/ml in Hepes buffer (pH 7.1). Approximately 10 μg of cesium chloride gradient purified linearized plasmid DNA was mixed with 750 μl of the infected cell suspension and placed on ice in an electroporation cuvette for 10 min before and immediately after electroporation at 200 volts and 500 μFD using a Bio-Rad Gene Pulser. The cells were then diluted in MEM containing 10% FBS and incubated at 37°C. After 2-3 days, to permit virus replication, transfected cells and supernatants were collected, frozen and thawed twice and sonicated for 20 sec to release virus. Putative recombinants were selected by plating the sonicated supernatants on TK^- 143 cells and overlaying with 1% agarose in growth medium containing 5-bromo-2'-deoxyuridine (25 μg/ml). After 3 days, the TK^- plaques were visualized by staining the monolayer with neutral red, picked individually and grown on BSC-1 cells to amplify virus. Recombinant VV were selected by screening the TK^- plaques for gIV expression by immunocytochemistry before replaquing and making viral stocks in $LMTK^-$ cells.

IX.A.4. Polyclonal and monoclonal antibody

gIV specific monoclonal antibody (MAb) production and characterization, in particular their reactivity with native or denatured gIV, neutralizing activity, and grouping based on competition binding assays have been described (Hughes et al. (1988) Arch. Virol., 103:47-60 and van Drunen Littel-van den Hurk et al. (1990) J. Gen. Virol., 71:2053-2063). Before use, MAb ascites fluids were clarified and filtered. Monospecific polyclonal gIV specific antisera produced in rabbits have been described (Hughes et al. (1988) supra).

IX.A.5. Protein expression

For immunoprecipitation, $LMTK^-$ cells were infected at a multiplicity of infection (MOI) of 5. At 10 hrs post infection, the cells were washed and incubated in cysteine-methionine free DMEM for 90 min before labeling with [^{35}S] cysteine-methionine (100 μCi/ml). After 4-8 hrs of labeling, the cells and/or medium was harvested. In pulse-chase experiments, cells were labelled at 10 hrs post infection with 150 μCi of [^{35}S] methionine-cysteine for 15 min. Depending on the specific experiment, either the cells were harvested immediately or the label was removed and cells were incubated for different time periods in DMEM containing an excess of cold methionine (chase). Proteins were immunoprecipitated from the medium or from the infected cells, lysed with modified RIPA buffer and analyzed by SDS-PAGE as previously described (van Drunen Littel-van den Hurk (1990) supra).

IX.A.6. Enzyme treatments

Immunoprecipitated proteins were eluted in 20 μl of 0.5% SDS by boiling for 3 min. The eluted proteins were digested with 20 mU of endo H in 0.125M sodium citrate pH 5.5, 0.1M 2-mercaptoethanol, 0.5mM phenylmethylsulphonyl fluoride and 0.1% SDS. For analysis by SDS-PAGE, the digested proteins were precipitated with ice-cold acetone, resuspended in electrophoresis sample buffer and boiled for 3 min before analysis (van Drunen Littel-van den Hurk

(1990) supra).

IX.A.7. Immunoperoxidase staining

LMTK$^-$ cells grown in 4 well Lab-Tek chamber slides were infected with the appropriate recombinant VV at an MOI of 5. After 16 hrs of incubation the cells were fixed with 3% paraformaldehyde for 15 minutes at 4°C (surface staining) and stained by immunoperoxidase staining procedure as previously described (Fitzpatrick et al. (1988) supra).

RESULTS

IX.B.

To examine the structure and function of different domains of gIV, the complete open reading frame and the mutated forms (internal deletions or truncations) of gIV gene (Fig. 15) were cloned into the VV expression vector pGS20 (Fig. 2) to generate recombinant VVs designated here as STgIV expressing wild-type gIV, and STgIVd1 to STgIVd9 expressing mutant proteins d1 to d9 respectively.

IX.B.1. Characterization of proteins made by recombinant VVS

To examine the product of the wild type gIV gene, LMTK$^-$ cells were infected with recombinant VV STgIV and metabolically labelled with [^{35}S] cysteine-methionine. For comparison with authentic gIV, MDBK cells were infected with BHV-1 and labelled similarly with [^{35}S] cysteine-methionine. The radiolabelled proteins were immunoprecipitated with rabbit anti-gIV antiserum and analyzed by SDS-PAGE under reducing conditions.

Radioimmunoprecipitation of recombinant pSTgIV VV infected cells revealed a major protein band of approximately 71 kDa molecular weight which comigrated with the authentic gIV protein produced in BHV-1 infected cells. No similar band was observed in uninfected cells or cells infected with wild-type VV. This suggests that recombinant gIV produced in LMTK$^-$ cells was post-translationally modified in a manner similar to authentic gIV. The proteins produced by the recombinants carrying deleted or truncated forms of gIV were also analyzed by SDS-PAGE under reducing conditions. The mutant forms of gIV protein d1-d9 were detected as single bands at approximately the expected molecular weights, except d7 which migrated more slowly than expected. This aberrant mobility of d7 protein appears to be due to the addition of O-linked oligosaccharides (Tikoo et al. unpublished data).

IX.B.2. Antigenic structure of gIV proteins

To examine the antigenic properties of wild type gIV, radiolabelled protein was immunoprecipitated from VV STgIV infected cell lysates with gIV-specific MAbs (Hughes at al. (1988) supra and van Drunen Littel-van Den Hurk at al. (1984)Virology, 135:466-479) and analyzed by SDS-PAGE under reducing conditions. In addition to the recognition of the recombinant gIV by MAbs directed against continuous epitopes Ib (Mab 9D6), IV (MAb 3D9S) and IIIa (MAb 10C2), the protein was also recognized by MAbs directed against discontinuous epitopes Ib (MAb 136), II (MAb 3E7), IIIc (MAb 2C8), IIId (MAb 3C1) and IIIb (MAb 4C1). This suggests that the antigenic structure of gIV produced in VV StgIV infected cells is similar to gIV produced by BHV-1 infected cells.

In order to locate the antigenic sites on the gIV glycoprotein, the mutated proteins were similarly immunoprecipitated from recombinant infected cell lysates with individual MAbs and analyzed by SDS-PAGE under reducing conditions. The results are as follows:

a) A truncated form of gIV (AAs 1-355), expressed by recombinant VV STgIVd1, which lacks 62 amino acids at the carboxy terminus including the transmembrane anchor sequence, reacted with all of the gIV specific MAbs recognizing both continuous and discontinuous epitopes.

b) A truncated form of gIV (AAs 1-320), expressed by recombinant W STgIVd2, which lacks 97 amino acids at the carboxy terminus, reacted with all of the MAbs, except 3D9S (which recognized a continuous epitope) and 136 (which recognized a discontinuous epitope). The reactivity of MAbs 2C8 and 4C1 to this protein was also reduced.

c) A truncated form of gIV (AAs 1-244), expressed by recombinant VV StgIVd3, which lacks 173 amino acids at the carboxy terminus reacted only with Mab 9D6, which recognize a continuous epitope.

d) A truncated form of gIV (AAs 1-216), expressed by recombinant W STgIVd4, which lacks 201 amino acids at the carboxy terminus, also reacted only with MAb 9D6.

e) A truncated form of gIV (AAS 1-164), expressed by recombinant W STgIVd5, which lacks 253 amino acids at the carboxy-terminus, did not react with any of the MAb.

f) A deleted form of gIV expressed by recombinant W STgIV6, which lacks 265 AAs from residue 90 to 354 in the

extracellular domain of gIV, also did not react with any of the MAbs.

g) A deleted form of gIV expressed by recombinant VV STgIVd7, which lacks 213 residues from AAs 32-244 in the extracellular region of gIV, reacted only with Mab 3D9S which recognize a continuous epitope.

h) A deleted form of gIV expressed by recombinant pSTgIVd8, which lacks 139 AAs from residue 218-355 in the extracellular region of gIV, reacted only with Mab 9D6.

i) A deleted from of gIV expressed by recombinant W STgIVd9, which lacks 112 residues from AAs 245-355 in the extracellular region of gIV reacted only with Mab 9D6.

These observations suggest that binding sites for Mab 9D6 and 3D9 lie between amino acid 164-216 and amino acid 320-355, respectively. In addition amino acids 244-320 are important for the formation of discontinuous epitopes recognized by MAbs 2C8 and 4C1, whereas amino acids 320-355 are critical for the formation of discontinuous epitope recognized by Mab 136.

IX.B.3. Secretion of truncated gIV proteins.

In order to determine whether truncated forms of gIV were efficiently secreted into the medium, LMTK$^-$ cells infected with recombinant VVs were labeled with [^{35}S] cysteine-methionine for 4-8 hrs beginning 10 hrs after infection. Cell culture supernatants were immunoprecipitated with rabbit anti-gIV polyclonal antiserum. Proteins expressed by recombinant VV STgIVd1 and VV STgIVd2 were detected in the medium where as proteins truncated at or upstream of amino acid 244 (VV STgIVd3 to VV STgIVd5) were never detected in the medium. This suggests that amino acid 244-320 are required for efficient secretion of the truncated gIV molecules and confirmed our previous observation concerning the location of transmembrane anchor domain between amino acids 361 to 389 (Tikoo et al. (1990) supra).

IX.C.1.

A number of strategies have been used to locate the antigenic sites of a viral glycoprotein. Since the induction of protective humoral immune response is dependent on the conformation of gIV, the approach of expressing deleted and truncated forms of gIV in mammalian cells by recombinant vaccinia viruses has allowed the mapping of the binding sites of different MAbs in gIV and study the effect of these mutations on the native structure of the glycoprotein (Fig. 16). A similar approach has been used to localize the functional domains of HSV-1 glycoprotein D (Cohen et al. (1988) J. Virol. 62:1932-1940).

To confirm the validity of this approach, insertion of the full-length gIV gene into vaccinia virus showed that gIV expressed by recombinant VV STgIV had an antigenic profile indistinguishable from authentic gIV synthesized after viral infection (Hughes et al. (1988) and van Drumen Littel-van den Hurk et al. (1986) supra). These results confirm and extend the observations previously reported for recombinant gIV expressed in transfected bovine cells (Tikoo et al. (1990) supra).

Previously, four antigenic domains of gIV were identified using a panel of MAbs (Hughes et al. (1988) and van Drunen Littel-van den Hurk et al. (1986) supra). Domain I consists of two epitopes; epitope Ia is a continuous epitope recognized by MAb 9D6 and epitope Ib is a discontinuous epitope recognized by MAb 136. The present results indicate that epitope Ia is located between residue 164-216 and a portion of epitope Ib is located between residue 320-355. The second portion of epitope Ib is located upstream of residue 245, perhaps upstream of residue 216 but downstream of residue 31. This assumption is based on the fact that recombinant VV STgIVd7 which expresses a mutant protein devoid of residues 32-244 is not recognized by MAb 136. In addition, competitive bidding experiments indicate that either these two epitopes share common amino acids or that they lie in close proximity to one another (Hughes et al. (1988) supra).

Domain II of gIV is represented by a discontinuous epitope which is recognized by MAB 3E7. This epitope is located upstream of residue 320 and at least a portion of the epitope is located upstream of residue 245. This is based on two observations. First, if the binding site is composed entirely of residues between 245-320, the protein expressed by recombinant VV STgIVd7 should be recognized by MAB 3E7. Second, the epitope is destroyed by the addition of reducing agents, and all of the cysteine residues that could possibly contribute to disulphide binding are located between residue 74 to 214.

Domain III is represented by four epitopes, three of which have been shown to be discontinuous (Hughes et al. (1988) supra). Analysis of the mutant proteins expressed by recombinant VV STgIVd2, VV STgIVd7 and VV STgIVd9 indicate that the binding site for Mab 10C2, which recognizes the continuous epitope IIIa, lies in close proximity to amino acids 244 and 245. The epitopes IIIB, IIIC and IIId recognized by conformation dependent Mabs 4C1, 2C8 and 3C1 respectively, are located between amino acid 19 to 320.

Domain IV is represented by a continuous epitope recognized by a non-neutralizing MAb 3D9S. This epitope was mapped between residues 320-355.

Formation of discontinuous epitopes depends on certain tertiary structures of gIV which in part involve disulphide bonds. The observation that the Mabs recognizing discontinuous epitopes (destroyed by reducing agent) react with residues 1-355 suggests that this polypeptide maintains its normal disulphide bonding pattern. Six of the seven gIV cysteine residues located within residues 75 to 213 probably play a role in the structure of these discontinuous epitopes. Interestingly, these six cysteine residues are readily aligned in all gIV homologs thus far identified (Tikoo et al. (1990) supra). All six cysteines are involved in intramolecular disulphide bond formation in HSV-1 gD (Wilcox et al. (1988) J. Virol. 62:1941-1947) and are suggested to be important for the structure and function of the protein (Long et al. (1990) J. Virol. 64:5542-5552). The cysteine at residue 376 is within the transmembrane domain of gIV and is not involved in the formation of these epitopes, indicating that this cysteine is not involved in intramolecular disulphide bonding in gIV required for attaining the proper tertiary structure. A similar observation has been made previously for the HSV-1 gD glycoprotein (Wilcox et al. (1988) supra).

Earlier studies have shown the presence of both N-linked and O-linked oligosaccharides in gIV (van Drunen Littel-van den Hurk et al. (1986) supra). In BHV-1 infected cells, N-linked oligosaccharides are processed from high mannose oligosaccharides present on precursor gIV (pgIV) to complex oligosaccharides of mature gIV which is transported to the surface of the infected cell and also incorporated into the virion envelope (Marshall et al. (1986) J. Virol. 57:745-753 and van Drunen Littel-van den Hurk (1986) supra). At 24 hrs postinfection, most of the protein is found in the mature form. Essentially similar transport and processing kinetics were observed for recombinant gIV produced by VV STgIV indicating that VV is an acceptable vector for expressing BHV-1 glycoproteins.

Processing and transport of a viral glycoprotein through the exocytic pathway is dependent on its conformational and structural signals, which may include the location of N-linked glycosylation sites, position of cysteine residues forming disulphide bonds that promote the juxtaposition of residues on the molecule, and amino acid residues required for membrane insertion, anchoring, local folding of monomers and formation of oligomers (Guan et al. (1985) Cell 42:489-496; Kreis et al. (1986) Cell 46:929-937; Rose et al. (1988) Ann. Rev. Cell Biol. 4:257-288 and Wilcox et al. (1988) supra). Alterations of any of these signals may affect processing, and/or transport of a glycoprotein. The results of this study indicate that the extent of processing of the genetically engineered gIV mutant proteins correlated with the transport of the proteins to the call surface/media. However, a loss in the ability to form discontinuous epitopes was not associated with the loss of transport of the mutant protein to the cell surface/media. All mutant proteins containing amino acids 245-320 (d1, d2, d7) were processed from precursor to product, contained endo H resistance oligosaccharides and were located on the surface of the cell or secreted into the medium when the transmembrane anchor sequence was also been deleted. These results suggest that these proteins retained signals necessary for the proper folding, processing and consequently transport of the protein to the cell surface. In contrast, all mutants lacking amino acids 245-320 (d3, d4, d5, d6, d8, d9) failed to be processed from precursor to product form and were not transported to the cell surface or secreted in the medium. In addition, virtually all of the oligosaccharides were of the high-mannose form indicating that these mutant proteins are retained in the endoplasmic reticulum. It is in this organellese that membrane-bound and secretory proteins acquire high-mannose oligosaccharides, fold and in many cases oligomerize (Rose et al. (1988) supra). Both misfolded and unassembled subunits are retained in the endoplasmic reticulum and prevented from further transport by interactions with resident cellular proteins (Rose et al. (1988) supra). The altered processing and transport of the mutants lacking amino acid 245-320 could be due to misfolding of the proteins, however, we could not detect protein aggregation (data not shown), as has been observed with the other misfolded proteins (Wilcox et al. (1988) supra). Alternatively, a block in transport could be due to the absence of required signals residing in residues 245-320. Preliminary studies indicate that the O-linked oligosaccharides are attached to serine/threonine located in this region (Tikoo et al. unpublished data). It is possible that the absence of either amino acid sequence or protein modifications present in this region may be responsible for the observed affects.

X.A. Animal trials were conducted with full-length gIV (gIVA) and truncated gIV (TgIVA) and results analyzed as described previously in VII above.

X.B. Results - Analysis of the serum samples obtained from the vaccinated animals showed that both the full-length gIV (gIV) and the truncated gIV (TgIV), prepared as in XI above, produced strong immune responses as measured by ELISA and plague reduction assays as set forth in Tables 5 and 6 below. Significantly nasal secretions also contain neutralizing antibody, as set forth in Table 6 below. Clinical examination indicated that gIV and TgIV significantly reduced virus shedding and sick-days. The placebo animals in every case succumbed to BHV-1 infection as indicated by conventional virus-shedding (Figure 13) and prolonged sickness (Figure 14).

Table 5

ELISA Assay							
				αgIV ELISA Titer			
Group	No.	Dose	Adjuvant	No. An.	21 Days	35 Days	45 Days
Placebo	1	-	Avridine	6	8	5	19
gIV	2	25μg	Avridine	8	24	1,076	4.5×10^5
TgIV	3	25μg	Avridine	8	28	380	4.9×10^4

Table 6

				Neutralization Titers				
Group	No.	Dose	Adjuvant	No. An.	21 Days	35 Days	45 Days	55 Days
					in Serum			in nasal secretions
Placebo	1	-	Avridine	6	<2	2.4	<2	1.4
gIV	2	25μg	Avridine	8	2.4	18	977	22
TgIV	3	25μg	Avridine	8	2.1	9	335	8

XI

XI.A. BHV-1 DNA Immunization Section

XI.A.1 Reagent Preparation

Plasmid DNA was produced by cultivating E. coli, strain Hb101, transformed with pRSO, Fitzpatrick, D.R. et al. (1988) Journal of Virology 62, 4239-4248, and pRSgIV, Tikoo, S.K. et al. (1990) Journal of Virology, 64, 5132-5142. Plasmid DNA was extracted and purified on CsCl gradients followed by dialysis against distilled water and ethanol precipitation. Purified plasmid was solubilized in 0.85% saline.

XI.A.1.2. Vaccination

Plasmid DNA was presented by intramuscular injection of four sites in the hind quarters of hereford calves. Volume of the injections was 2 ml with plasmid at a concentration of 62.5 μg/ml. Venous blood was drawn on regular intervals the presence of BHV-1 gIV-specific IgG antibody was determined by ELISA, western blots and neutralization assays.

XI.B. Results

A gIV gene-specific immune response has been demonstrated by Western blots and IgG ELISA titres of 3200 have been attained. Plaque-reduction assays indicate serum neutralizing titres as high as 48 (a titre of 16 correlated highly with protection from disease).

XII

Use of recombinant BHV-1 proteins for diagnostic purposes.

XII.A. The recombinant BHV-1 gI, gIII or gIV can be used as antigens in standard immunological assays, for example ELISA tests, to indicate the presence of antibodies to BHV-1. In this manner, the immunological status of an animal can be assessed with respect to present infection or predisposition to BHV-1.

The recombinant gI, gIII or gIV proteins were diluted in sodium carbonate buffer pH 9.6 and used to coat the wells of an ELISA plate at concentrations ranging from 0.1 to 1μg of protein/well. After incubating for a minimum of 1 hour,

the plates were washed and dilutions of animal sera added to the plate in a serial fashion. The processing of the ELISA proceeded as described in example X.

XII.B. The developed ELISA plate indicated that animals infected by BHV-1 had detectable levels of antisera specific for gI, gIII or gIV and any one of these recombinant BHV-1 proteins would be suitable for use in the diagnosis of BHV-1 infection.

DEPOSIT OF BIOLOGICAL MATERIALS

The following materials have been deposited or will be deposited with the American Type Culture Collection (ATCC), 12301 Parklawn Drive, Rockville, Maryland 20852, U.S.A. during the pendancy of this application as necessary. These deposits will be maintained under the terms of the Budapest Treaty on the deposit of microorganisms. The nucleotide sequences of the deposited materials are incorporated by reference herein, as well as the sequences of polypeptides encoded thereby. In the event off any discrepancy between a sequence expressly disclosed herein and a deposited sequence, the deposited sequence is controlling. The deposit off the sequence is not the grant of a license to make, use or sell any of the deposited materials.

Material	Accession Number	Deposit Date
1E11-1F6	HB 9774	July 22, 1988
1D6-G11	HB 9775	July 22, 1988
1G6-2D9	HB 9776	July 22, 1988
pVV-1/gI		December 9, 1992
pVV-1/gIII		December 9, 1992
pG4HUNEO	ATCC 69076	September 29, 1992
VAC-I	VR 2223	July 22, 1988
VAC-III	VA 2224	July 22, 1988

While the present invention has been illustrated above by certain specific embodiments, it is not intended that the specific examples should limit the scope of the invention as described in the appended claims.

Claims

1. A vaccine composition comprising a pharmaceutically acceptable vehicle and at least one recombinant subunit antigen comprising a truncated bovine herpesvirus type 1 (BHV-1) gIV.

2. The vaccine composition of claim 1 wherein said composition further comprises one or more antigenic determinants of BHV-1 gI, gIII or a second gIV.

3. The vaccine composition of claim 2 wherein said composition comprises of truncated BHV-1 gIV and one or more other antigenic determinants of BHV-1 gIII.

4. The vaccine composition of claim 2 wherein said composition comprises of truncated BHV-1 gIV and one or more other antigenic determinants of a second BHV-1 gIV.

5. The vaccine composition of claim 2 wherein said composition comprises truncated BHV-1 gIV and one or more antigenic determinants of BHV-1 gI.

6. The vaccine composition of claim 1 further comprising an adjuvant.

7. A nucleotide sequence encoding a truncated subunit antigenic protein BHV-1 gIV substantially homologous and functionally equivalent to a truncated form of a contiguous nucleotide sequence depicted in Figure 1.

8. The nucleotide sequence of claim 7 encoding the consecutive amino acid sequence 1-355 which lacks 62 amino acids at the carboxy terminus including the transmembrane anchor sequence.

9. A DNA construct comprising an expression cassette comprised of:

(a) a DNA coding sequence for a polypeptide comprising a truncated BHV-1 gIV glycoprotein; and
(b) control sequences that are operably linked to said coding sequence whereby said coding sequence can be transcribed and translated in a host cell, and at least one of said control sequences is heterologous to said coding sequence.

10. The DNA construct of claim 9 wherein, at least one of said control sequences is a stop condon in the reading frame immediately preceding the putative membrane spanning region of said mature polypeptide.

11. A host stably transformed by a DNA construct according to claim 9.

12. The host of claim 11 wherein said host cell is a procaryote.

13. The host of claim 12 wherein said procaryote is E. coli.

14. The host of claim 11 wherein said host cell is a virus.

15. The host of claim 14 wherein said virus is a recombinant vaccinia virus, baculovirus or adenovirus.

16. The host of claim 11 wherein said host is a eucaryote.

17. The host of claim 16 wherein said eucaryote is an insect.

18. The host of claim 16 wherein said eucaryote is a mammalian cell.

19. The host of claim 18 wherein said mammalian cell is transformed with a recombinant adenovirus vector.

20. The host of claim 18 wherein said mammalian cell is transformed with a recombinant Rous sarcoma virus vector.

21. The host of claim 18 wherein said mammalian cell is transformed with a recombinant simian virus vector.

22. A method of producing a recombinant truncated BHV-1 gIV polypeptide comprising:

(a) providing a population of host cells according to claim 11; and
(b) growing said population of cells under conditions whereby the polypeptide encoded by said expression cassette is expressed and secreted and optionally;
(c) recovering truncated BHV-1 gIV polypeptide from the growth media.

23. A method of treating or preventing BHV-1 infection in a bovine host comprising administering to said bovine host a therapeutically effective amount of a vaccine composition according to claim 1.

24. A method of treating or preventing BHV-1 infection in a bovine host comprising administering to said bovine host a therapeutically effective amount of a vaccine composition according to claim 2.

25. A method for co-treating or -preventing a BHV-1 infection and a second bacterial or viral infection in a bovine host comprises administering to said bovine host a therapeutically effective mount of (1) a vaccine composition comprising at least one recombinant subunit antigen of BHV-1 gIV, and (2) a vaccine against said second infection.

26. The method of claim 25 wherein (1) is a vaccine composition of claim 1 or 31.

27. The method according to claim 25, wherein said second infection is of Posteurella haemolytica or Haemophilus somnus, parainfluenza virus, coronavirus, rotavirus, adenovirus, bovine respiratory syncytial virus and bovine diarrhea virus.

28. A vaccine composition for co-treating or -preventing a BHV-1 infection and a second bacterial or viral infection in a bovine host comprises a therapeutically effective amount of (1) a vaccine composition comprising at least one recombinant subunit antigen of BHV-1 gIV, and (2) a vaccine against a second bacterial or viral infection.

29. The vaccine of claim 28 wherein (1) is a vaccine composition of claim 1 or 30.

30. A vaccine composition comprising a pharmaceutically acceptable vehicle and a subunit antigen comprising recombinant truncated BHV-1 gIV of 1-355 amino acids of gIV but lacking 62 amino acids at the carboxy terminus including the transmembrane anchor sequence.

31. A vaccine composition for nucleic acid immunization comprising a nucleic acid sequence or encoding a protein substantially homologous to a BHV-1 or a DNA construct comprising an expression cassette comprised of:

(a) a DNA coding sequence for a polypeptide containing at least one antigenic determinant of at least one recombinant BHV-1 glycoprotein, gI, gIII or gIV or immunogenic fragment thereof; and
(b) control sequences that are operably linked to said coding sequence whereby said coding sequence can be transcribed and translated in a host cell, and at last one of said control sequences is heterologous to said coding sequence.

32. The method of treating or preventing BHV-1 infection in a bovine host comprising administering to said bovine host a therapeutically effective amount of a vaccine composition according to claim 31.

33. A protein comprising truncated BHV-1 gIV.

34. The protein of claim 33 having the amino acids encoded by the nucleotide sequence of claim 7 or 8.

35. A method for determining the presence or absence of or concentration of antibodies for BHV-1 in a sample by employing an immunoassay, said immunoassay characterized by using recombinant antigenic BHV-1 gI, gIII and/or gIV reactive with said antibodies as a reagent in said immunoassay, whereby a complex of said antibodies and said recombinant antigenic BHV-1 gI, gIII and/or gIV is formed and determining the presence or absence of or concentration of said complex formed as indicative of the presence or absence of or concentration of said antibodies.

BHV-1 gIV: Sequence Range: 1 to 1405

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          10         20         30         40         50         60         70
GGG CCG CAG CCC CGG CTG GGT ATA TAT CCC CGA CGG GCG ACT AGA GAT ACA CTC GCC CCG CGC GGC TGC TGC

      80         90        100        110        120        130        140
GAG CGG GCG AAC ATG CAA GGG CCG ACA TTG GCC GTG CTG GGC GCG CTG CTC GCC GTT GCG GTG AGC TTG CCT
            M   Q   G   P   T   L   A   V   L   G   A   L   L   A   V   A   V   S   L   P>

    150        160        170        180        190        200        210
ACA CCC GCG CCG CGG GTG ACG GTA TAC GTC GAC CCG CCG GCG TAC CCG ATG CCG CGA TAC AAC TAC ACT GAA
 T   P   A   P   R   V   T   V   Y   V   D   P   P   A   Y   P   M   P   R   Y   N   Y   T   E>

  220        230        240        250        260        270        280
CGC TGG CAC ACT ACC GGG CCC ATA CCG TCG CCC TTC GCA GAC GGC CGC GAG CAG CCC GTC GAG GTG CGC TAC
 R   W   H   T   T   G   P   I   P   S   P   F   A   D   G   R   E   Q   P   V   E   V   R   Y>

290        300        310        320        330        340        350        360
GCG ACG AGC GCG GCG GCG TGC GAC ATG CTG GCG CTG ATC GCA GAC CCG CAG GTG GGG CGC ACG CTG TGG GAA
 A   T   S   A   A   A   C   D   M   L   A   L   I   A   D   P   Q   V   G   R   T   L   W   E>

        370        380        390        400        410        420        430
GCG GTA CGC CGG CAC GCG CGC GCG TAC AAC GCC ACG GTC ATA TGG TAC AAG ATC GAG AGC GGG TGC GCC CGG
 A   V   R   R   H   A   R   A   Y   N   A   T   V   I   W   Y   K   I   E   S   G   C   A   R>

      440        450        460        470        480        490        500
CCG CTG TAC TAC ATG GAG TAC ACC GAG TGC GAG CCC AGG AAG CAC TTT GGG TAC TGC CGC TAC CGC ACA CCC
 P   L   Y   Y   M   E   Y   T   E   C   E   P   R   K   H   F   G   Y   C   R   Y   R   T   P>

  510        520        530        540        550        560        570
CCG TTT TGG GAC AGC TTC CTG GCG GGC TTC GCC TAC CCC ACG GAC GAC GAG CTG GGA CTG ATT ATG GCG GCG
 P   F   W   D   S   F   L   A   G   F   A   Y   P   T   D   D   E   L   G   L   I   M   A   A>

580        590        600        610        620        630        640
CCC GCG CGG CTC GTC GAG GGC CAG TAC CGA CGC GCG CTG TAC ATC GAC GGC ACG GTC GCC TAT ACA GAT TTC
 P   A   R   L   V   E   G   Q   Y   R   R   A   L   Y   I   D   G   T   V   A   Y   T   D   F>
```

Figure 1-1

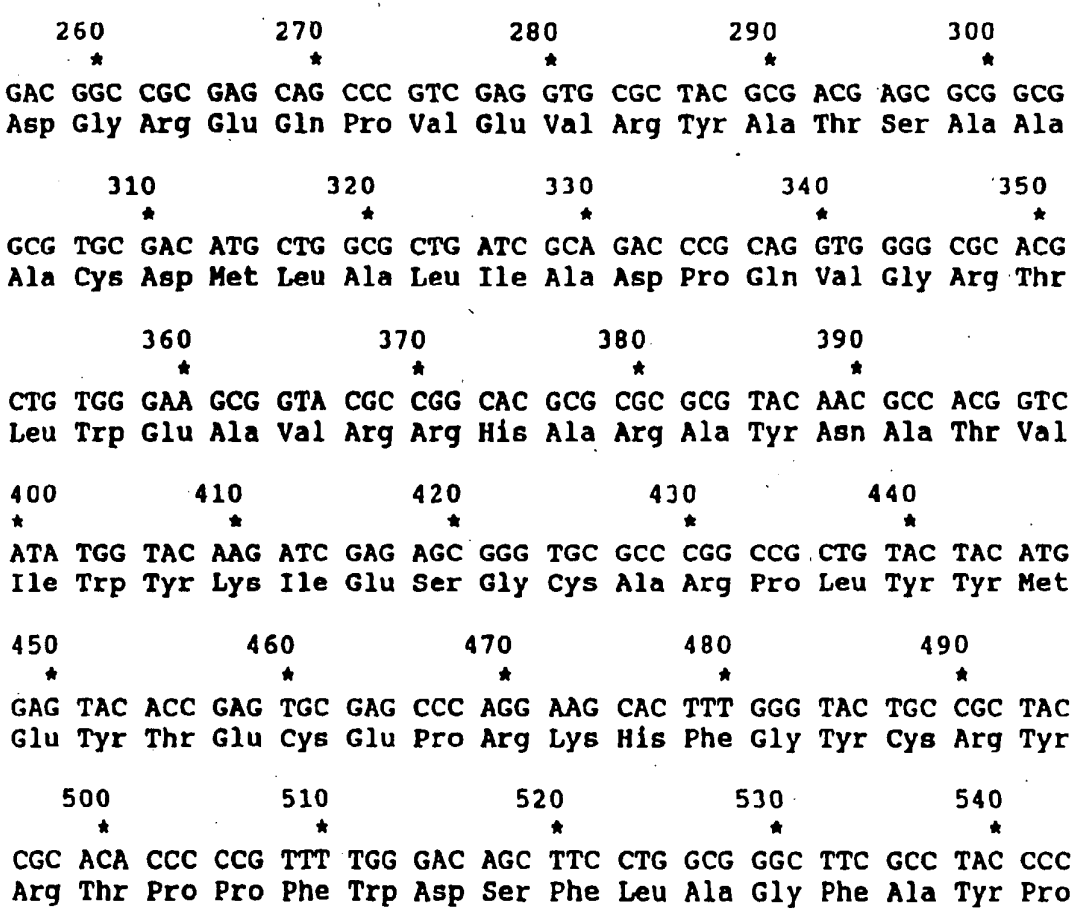

Figure 1-2

```
      550          560          570          580          590
        *            *            *            *            *
ACG GAC GAC GAG CTG GGA CTG ATT ATG GCG GCG CCC GCG CGG CTC GTC
Thr Asp Asp Glu Leu Gly Leu Ile Met Ala Ala Pro Ala Arg Leu Val

        600          610          620          630
          *            *            *            *
GAG GGC CAG TAC CGA CGC GCG CTG TAC ATC GAC GGC ACG GTC GCC TAT
Glu Gly Gln Tyr Arg Arg Ala Leu Tyr Ile Asp Gly Thr Val Ala Tyr

640         650          660          670          680
*             *            *            *            *
ACA GAT TTC ATG GTT TCG CTG CCG GCC GGG GAC TGC TGG TTC TCG AAA
Thr Asp Phe Met Val Ser Leu Pro Ala Gly Asp Cys Trp Phe Ser Lys

690           700          710          720          730
  *             *            *            *            *
CTC GGC GCG GCT CGC GGG TAC ACC TTT GGC GCG TGC TTC CCG GCC CGG
Leu Gly Ala Ala Arg Gly Tyr Thr Phe Gly Ala Cys Phe Pro Ala Arg

   740          750          760          770          780
     *            *            *            *            *
GAT TAC GAG CAA AAG AAG GTT CTG CGC CTG ACG TAT CTC ACG CAG TAC
Asp Tyr Glu Gln Lys Lys Val Leu Arg Leu Thr Tyr Leu Thr Gln Tyr

      790          800          810          820          830
        *            *            *            *            *
TAC CCG CAG GAG GCA CAC AAG GCC ATA GTC GAC TAC TGG TTC ATG CGC
Tyr Pro Gln Glu Ala His Lys Ala Ile Val Asp Tyr Trp Phe Met Arg
```

Figure 1-3

```
        840           850           860           870
         *             *             *             *
CAC GGG GGC GTC GTT CCG CCG TAT TTT GAG GAG TCG AAG GGC TAC GAG
His Gly Gly Val Val Pro Pro Tyr Phe Glu Glu Ser Lys Gly Tyr Glu

880         890           900           910           920
*            *             *             *             *
CCG CCG CCT GCC GCC GAT GGG GGT TCC CCC GCG CCA CCC GGC GAC GAC
Pro Pro Pro Ala Ala Asp Gly Gly Ser Pro Ala Pro Pro Gly Asp Asp

930           940           950           960           970
  *             *             *             *             *
GAG GCC CGC GAG GAT GAA GGG GAG ACC GAG GAC GGG GCA GCC GGG CGG
Glu Ala Arg Glu Asp Glu Gly Glu Thr Glu Asp Gly Ala Ala Gly Arg

   980           990           1000          1010          1020
    *             *             *             *             *
GAG GGC AAC GGC GGC CCC CCA GGA CCC GAA GGC GAC GGC GAG AGT CAG
Glu Gly Asn Gly Gly Pro Pro Gly Pro Glu Gly Asp Gly Glu Ser Gln

     1030          1040          1050          1060          1070
      *             *             *             *             *
ACC CCC GAA GCC AAC GGA GGC GCC GAG GGC GAG CCG AAA CCC GGC CCC
Thr Pro Glu Ala Asn Gly Gly Ala Glu Gly Glu Pro Lys Pro Gly Pro

      1080          1090          1100          1110
       *             *             *             *
AGC CCC GAC GCC GAC CGC CCC GAA GGC TGG CCG AGC CTC GAA GCC ATC
Ser Pro Asp Ala Asp Arg Pro Glu Gly Trp Pro Ser Leu Glu Ala Ile
```

Figure 1-4

```
1120      1130         1140          1150         1160
*           *            *             *            *
ACG CAC CCC CCG CCC GCC CCC GCT ACG CCC GCG GCC CCC GAC GCC GTG
Thr His Pro Pro Pro Ala Pro Ala Thr Pro Ala Ala Pro Asp Ala Val

1170         1180         1190         1200         1210
  *            *            *            *            *
CCG GTC AGC GTC GGG ATC GGC ATT GCG GCT GCG GCG ATC GCG TGC GTG
Pro Val Ser Val Gly Ile Gly Ile Ala Ala Ala Ala Ile Ala Cys Val

  1220         1230         1240         1250         1260
     *            *            *            *            *
GCC GCC GCC GCC GCC GGC GCG TAC TTC GTC TAT ACG CGC CGG CGC GGT
Ala Ala Ala Ala Ala Gly Ala Tyr Phe Val Tyr Thr Arg Arg Arg Gly

     1270         1280         1290         1300         1310
        *            *            *            *            *
GCG GGT CCG CTG CCC AGA AAG CCA AAA AAG CTG CCG GCC TTT GGC AAC
Ala Gly Pro Leu Pro Arg Lys Pro Lys Lys Leu Pro Ala Phe Gly Asn

       1320         1330         1340         1350         1360
          *            *            *            *            *
GTC AAC TAC AGC GCG CTG CCC GGG TGAGCGGCCT AGGCCCTCCC CCGACCGCCC
Val Asn Tyr Ser Ala Leu Pro Gly

 1370         1380         1390         1400
    *            *            *            *
CCTTTGCTCC TAGCCCCGGC TCCTGCCGAG CCGCGCGGGG
```

Figure 1-5

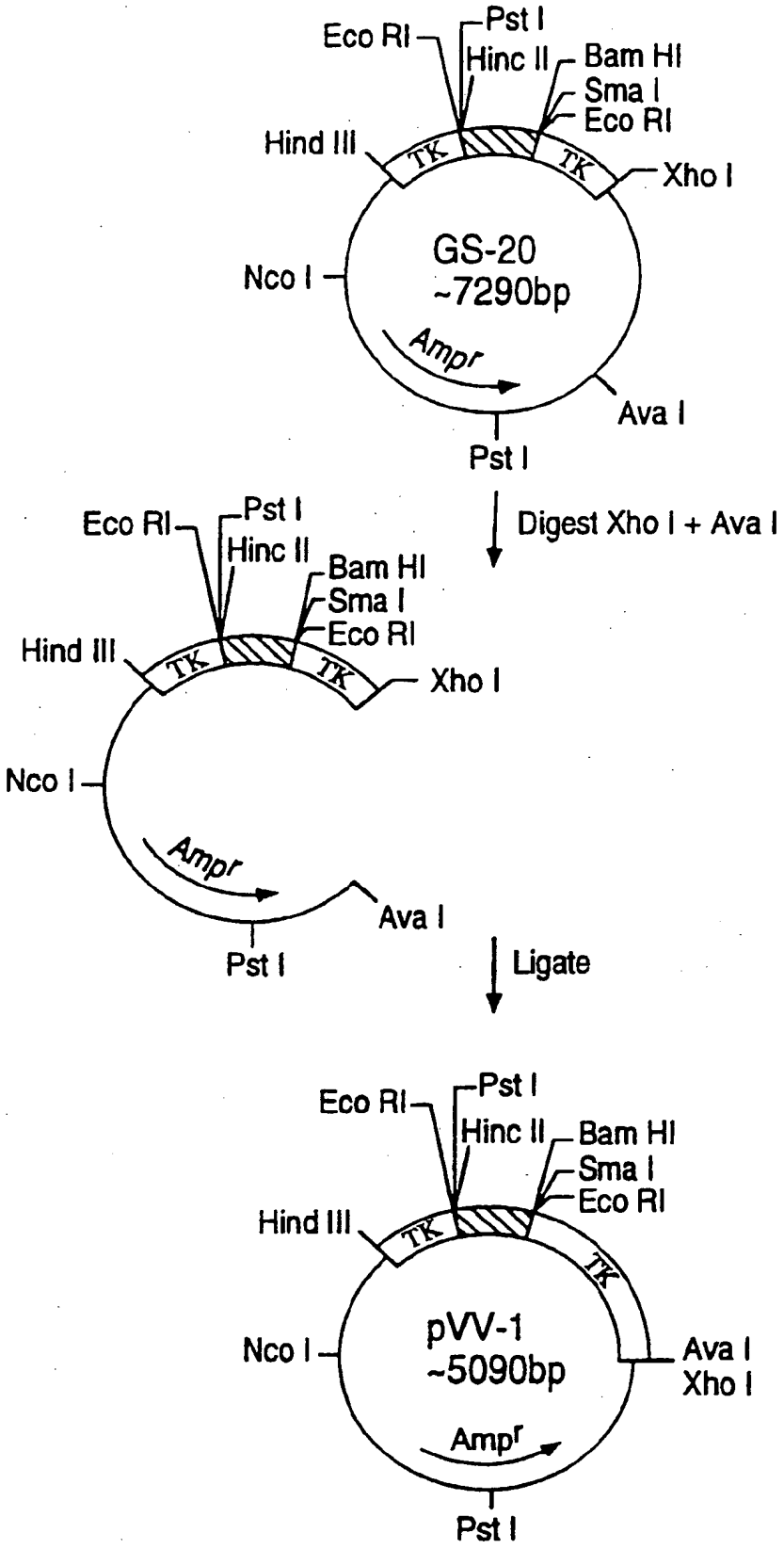

FIG. 2

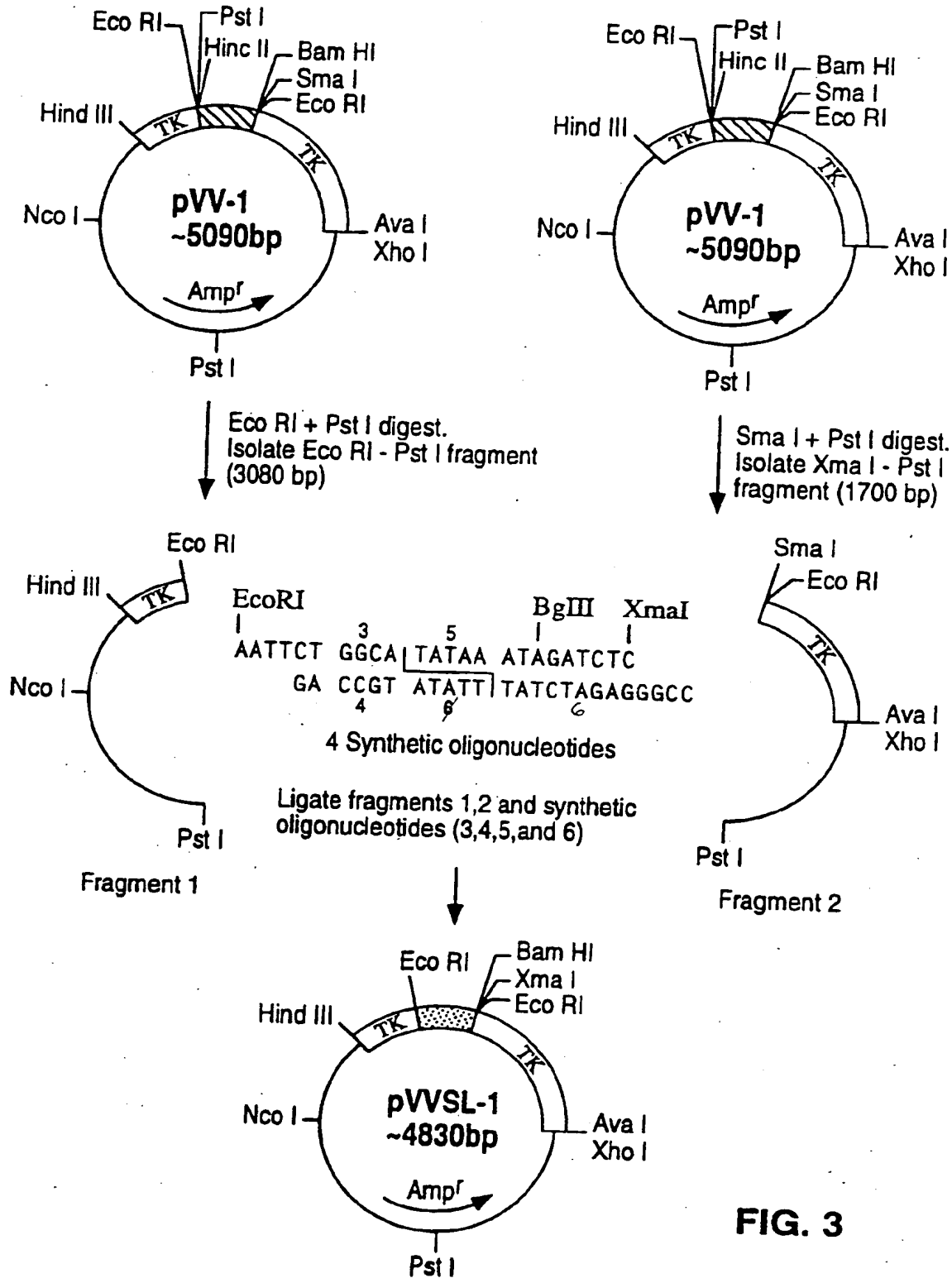

FIG. 3

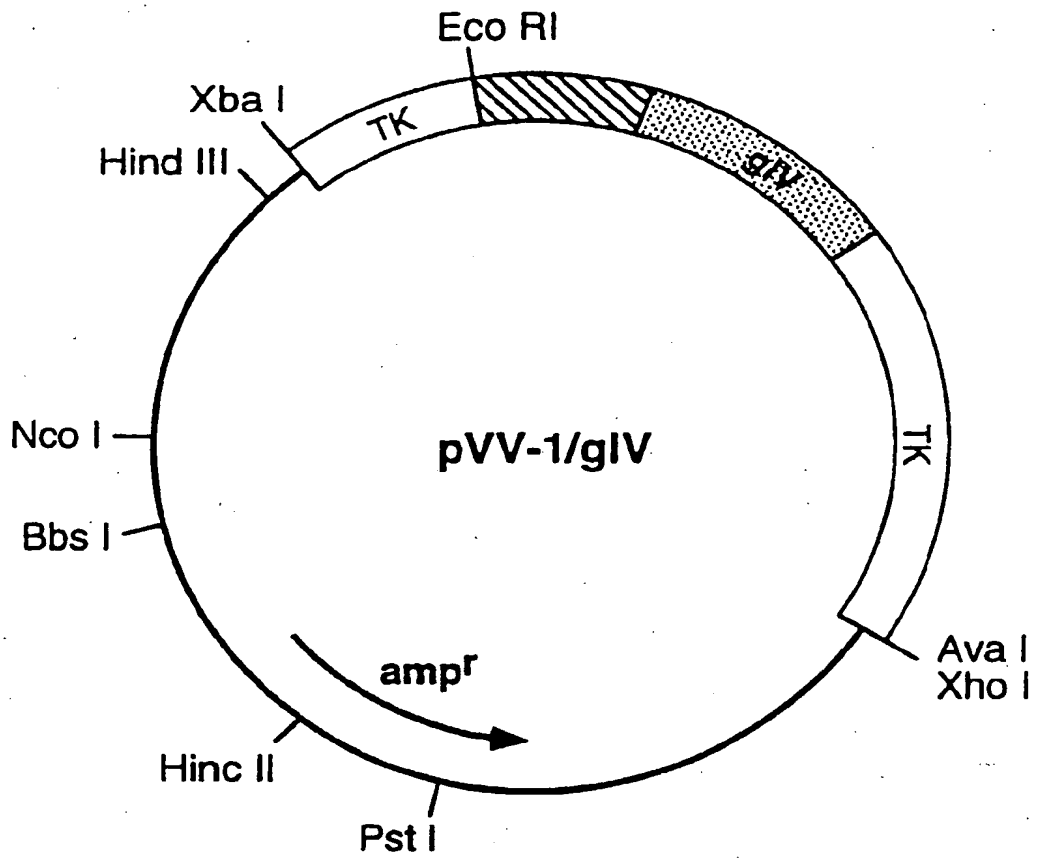

FIG. 4

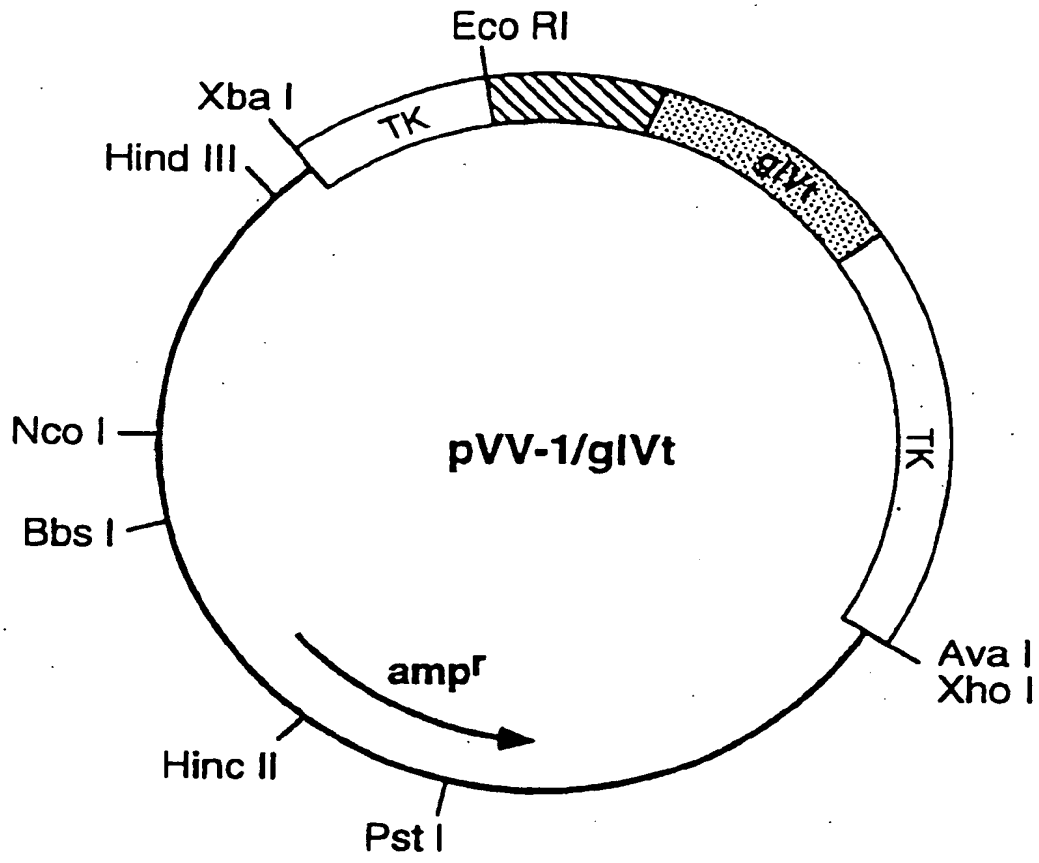

FIG. 5

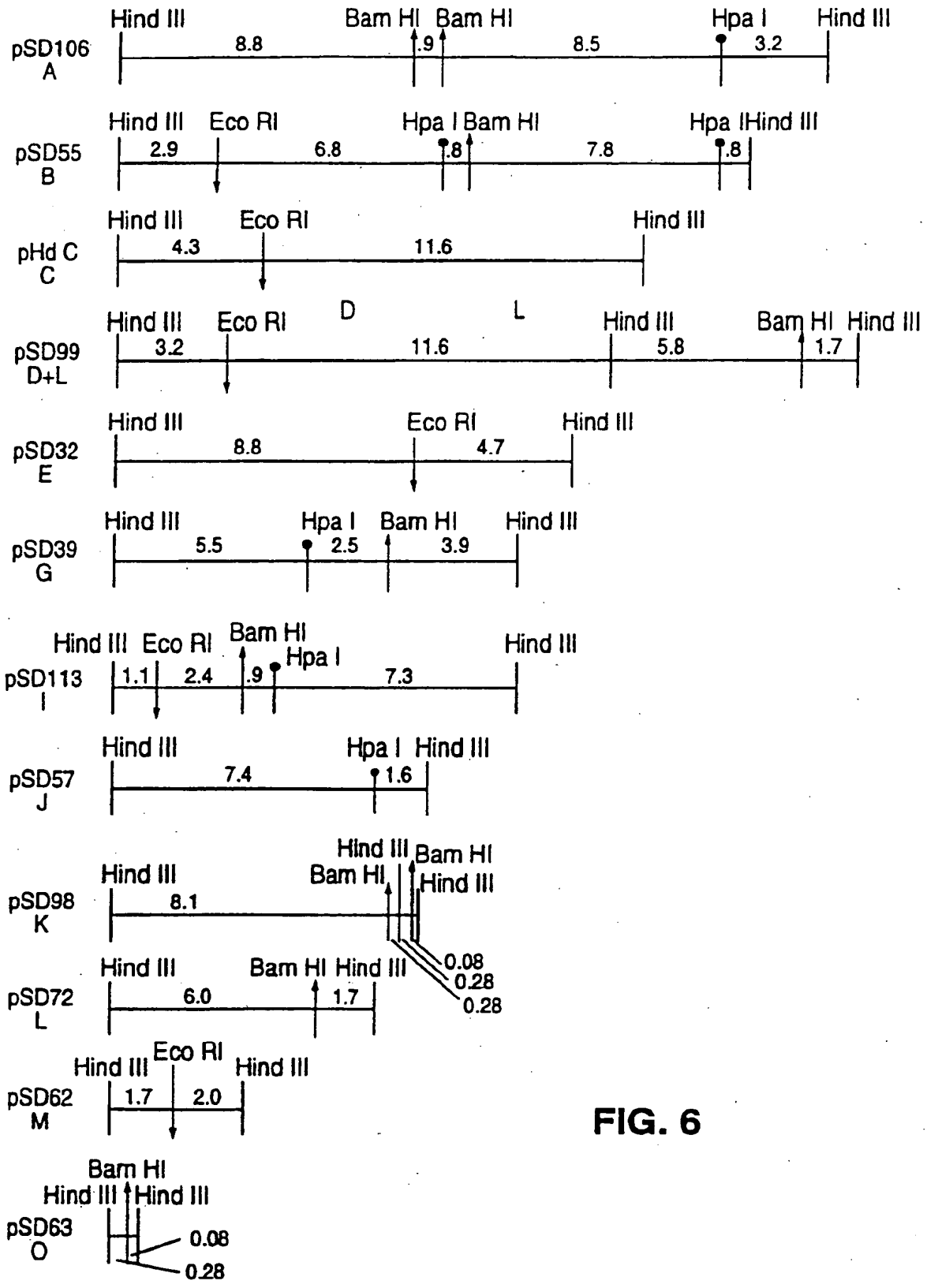

FIG. 6

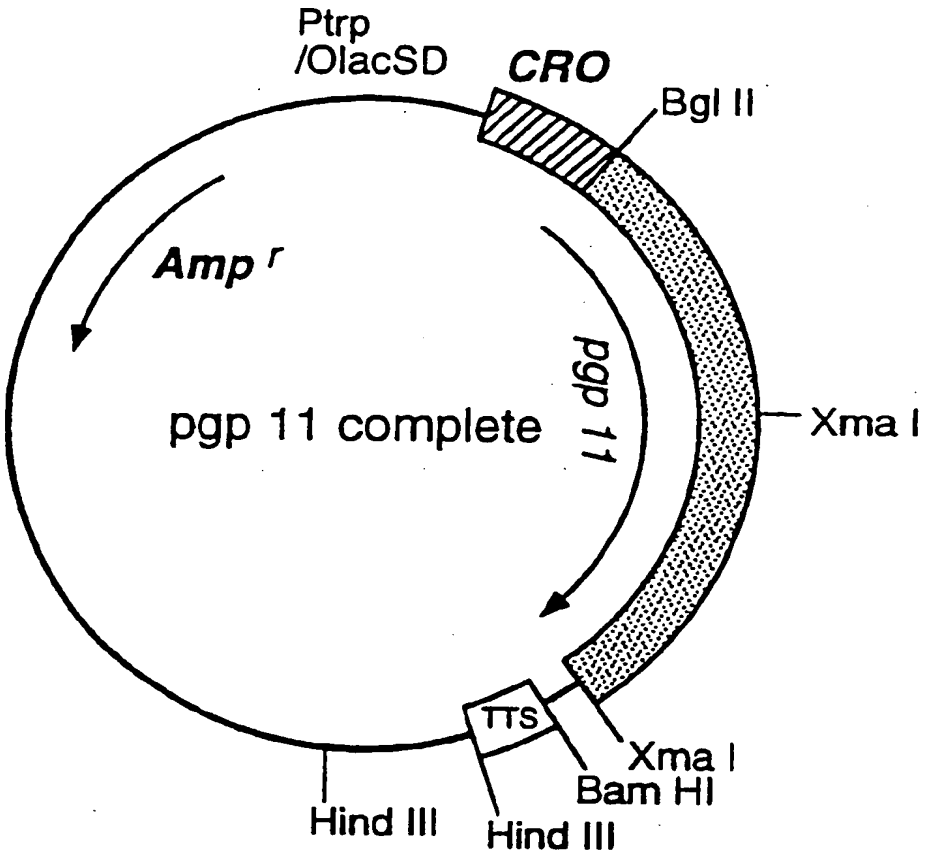

FIG. 7

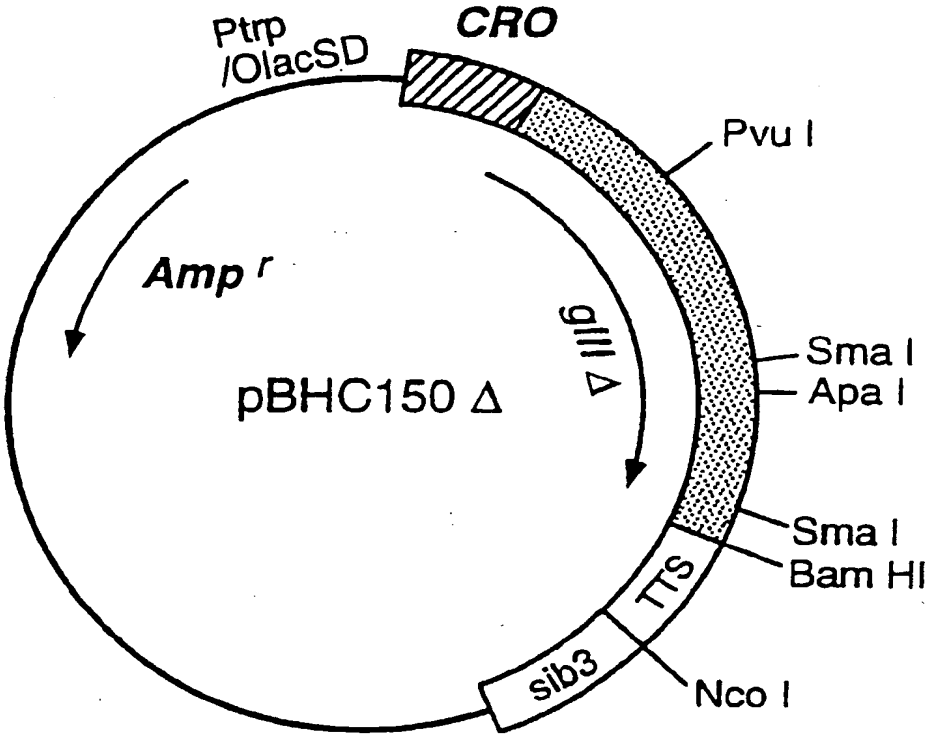

FIG. 8

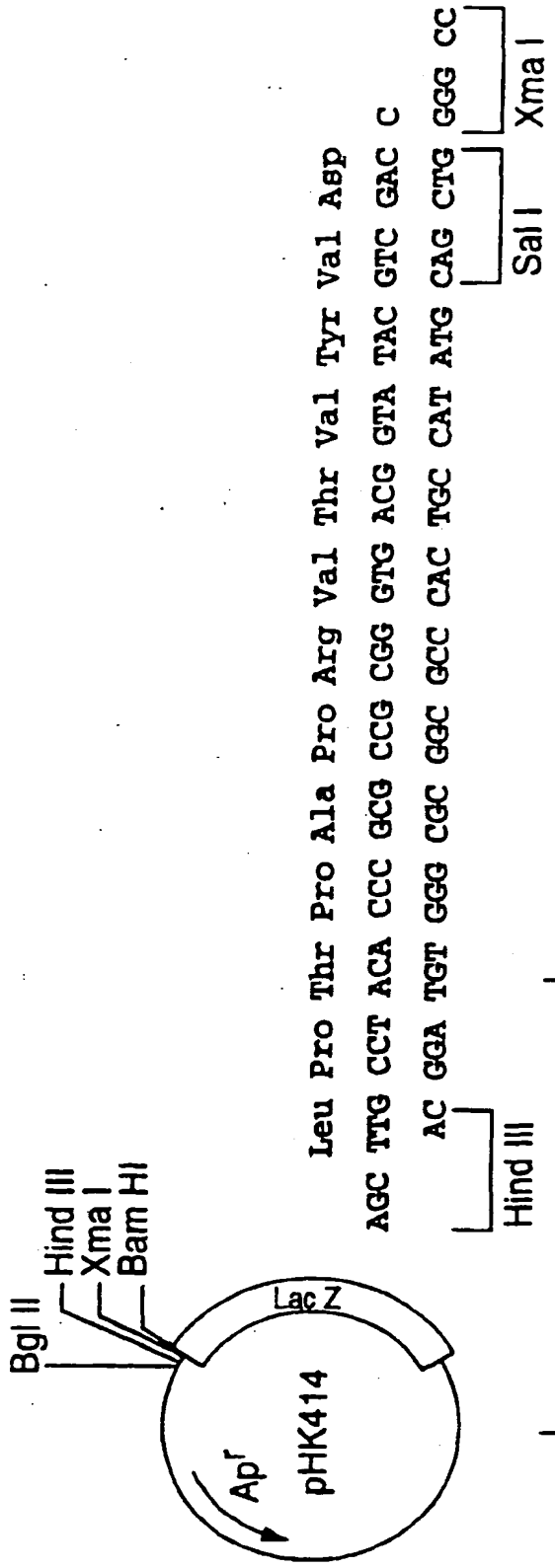

FIG. 9A

FIG. 9B

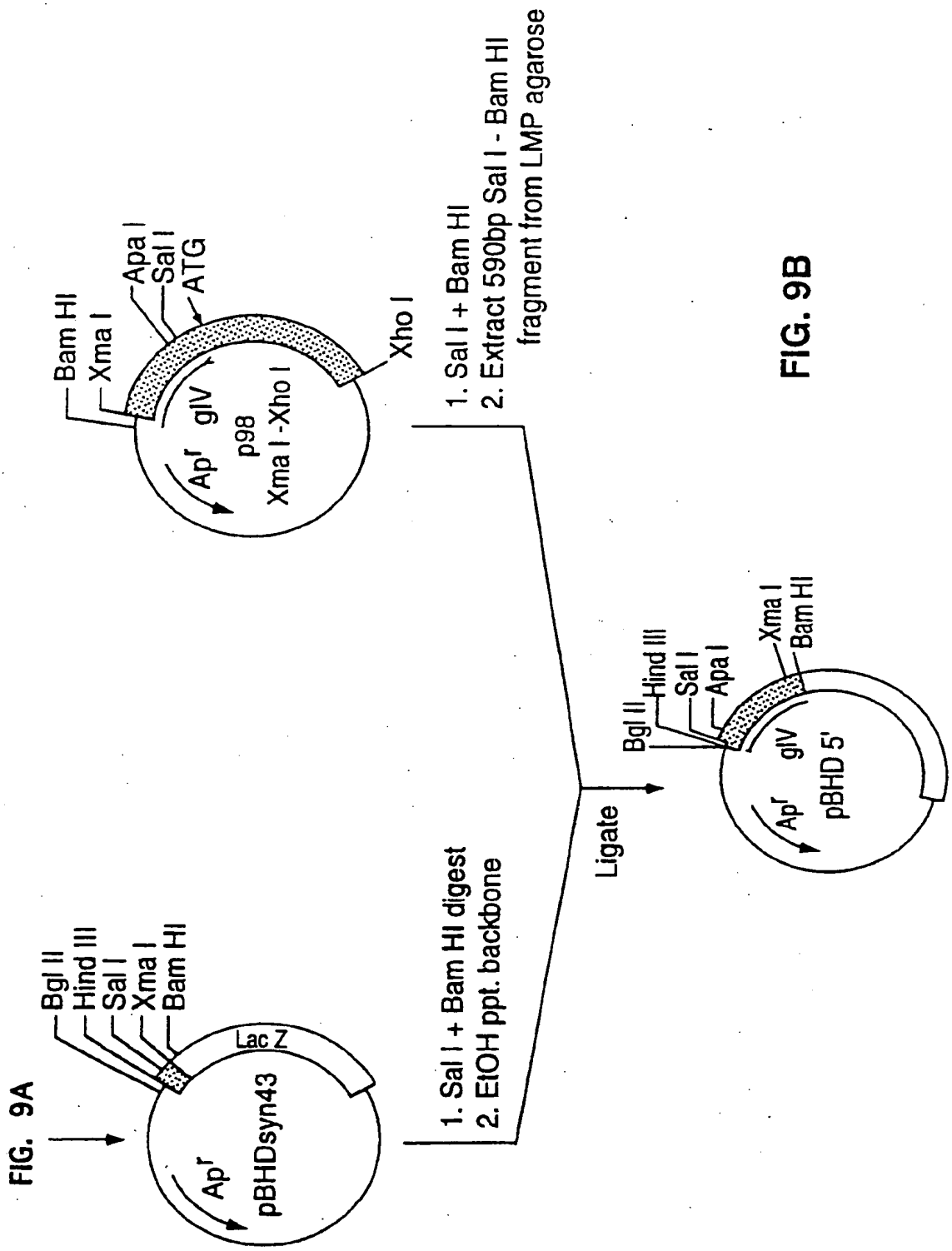

FIG. 9A

FIG. 9B

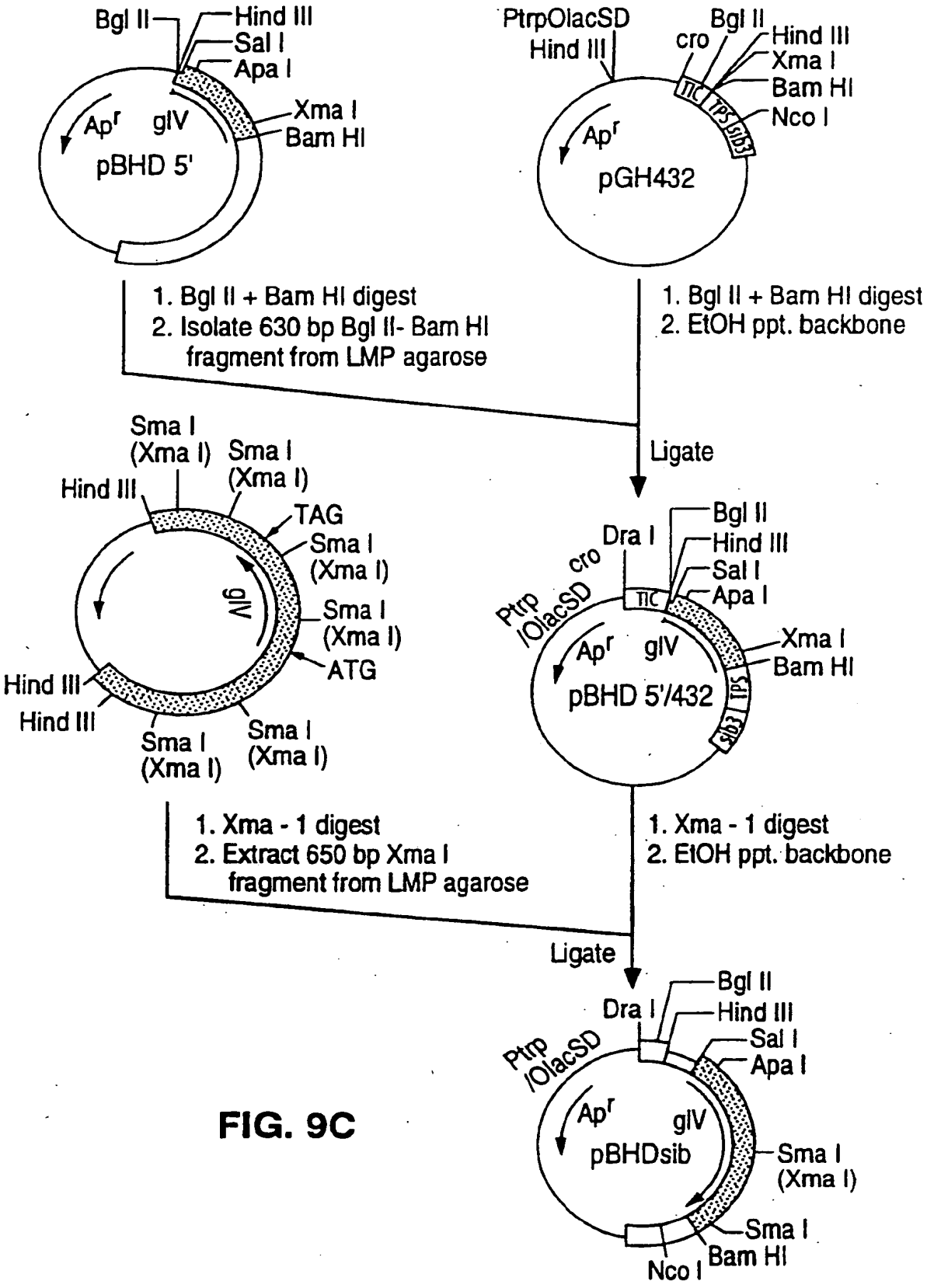

FIG. 9C

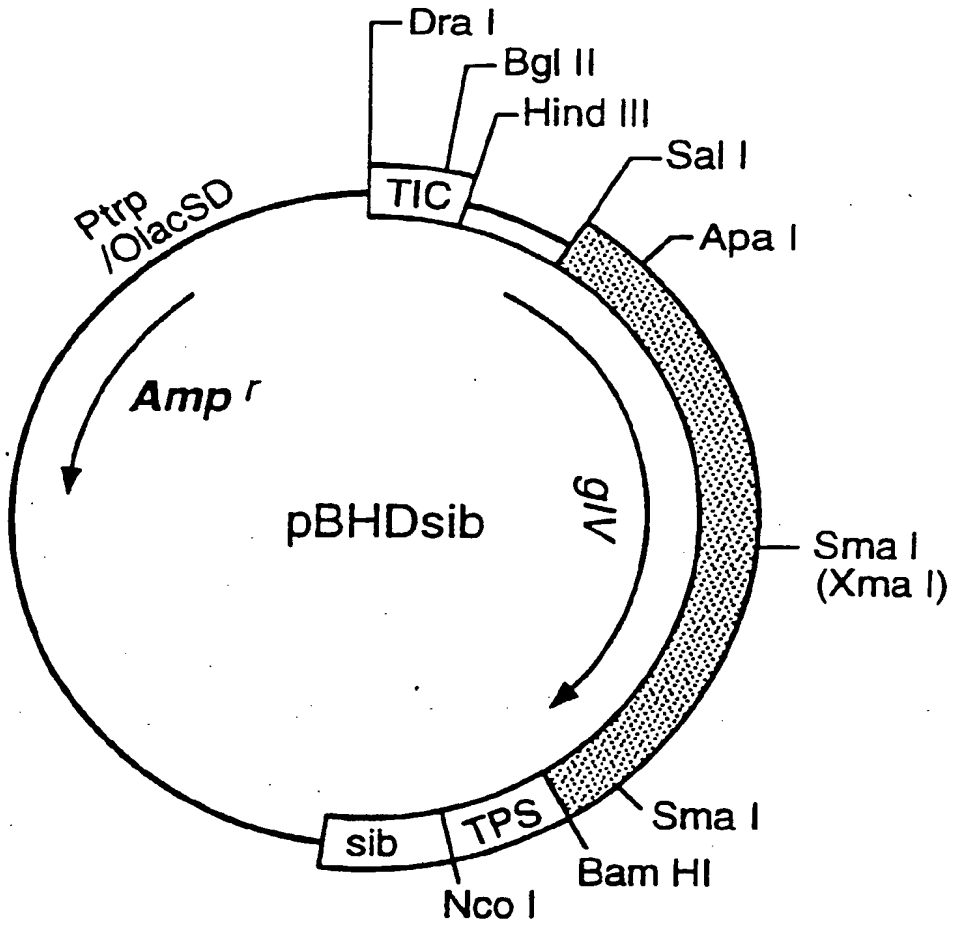

FIG. 10

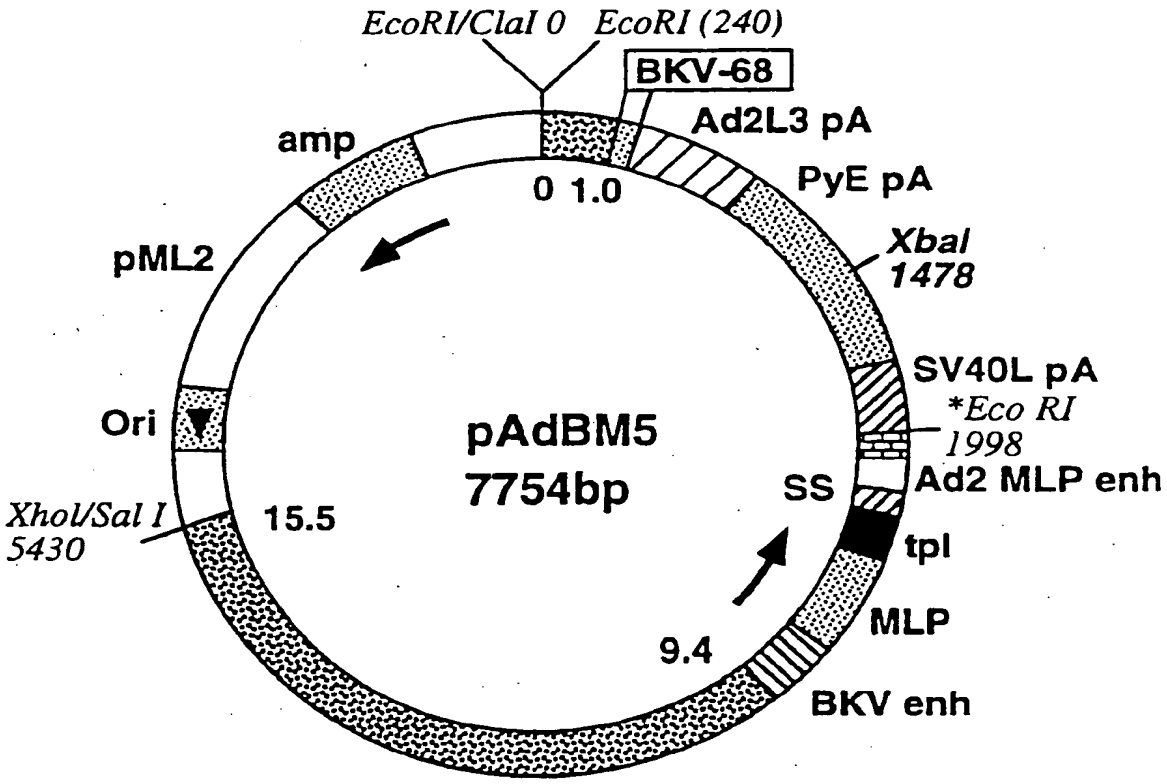

FIG.11

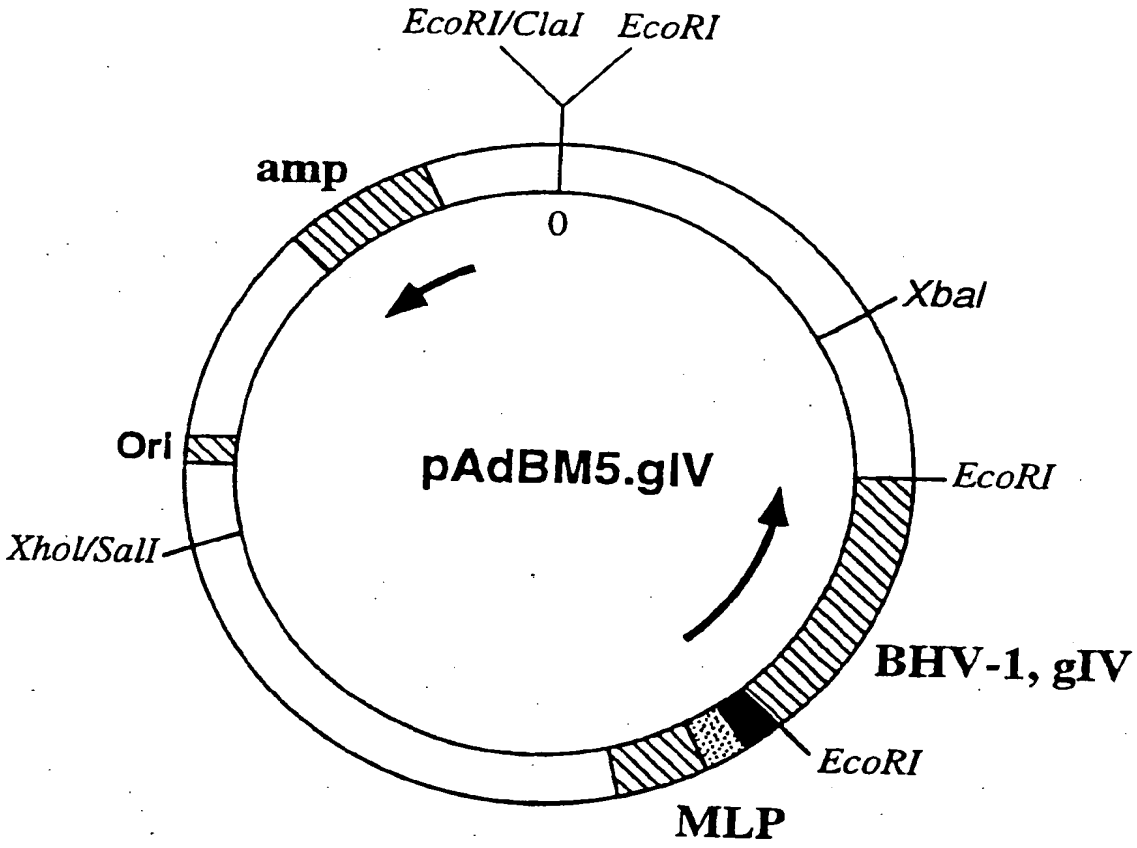

FIG. 12

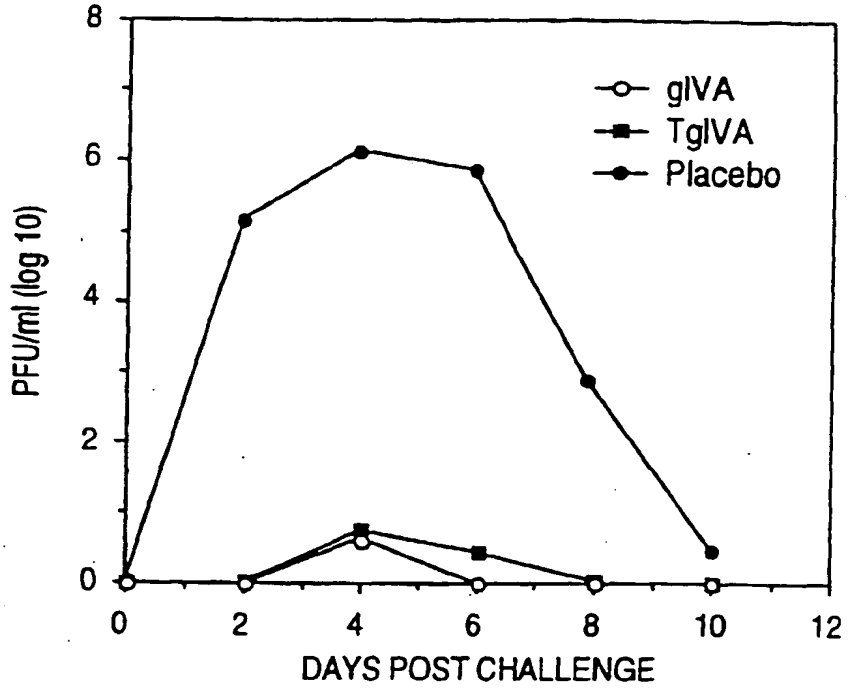

FIG. 13

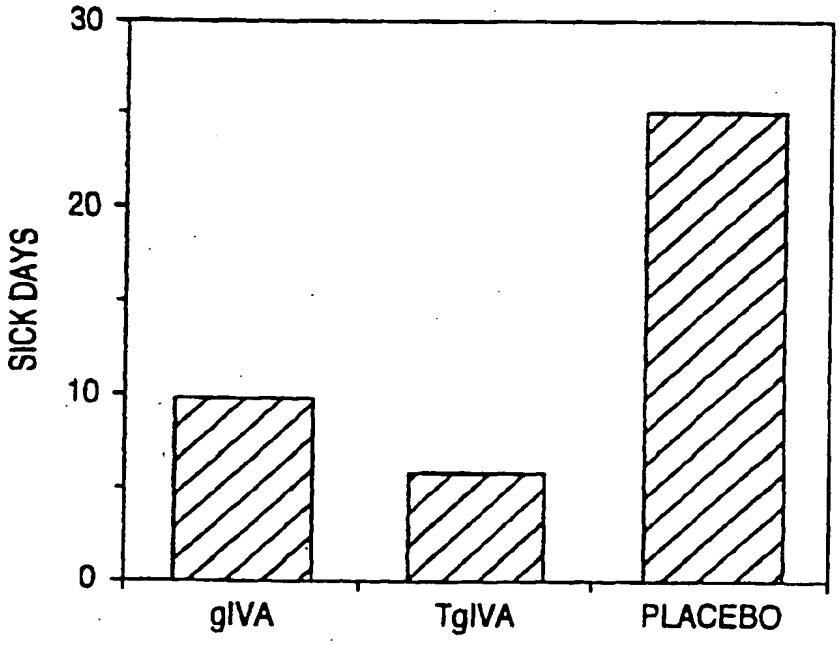

FIG. 14

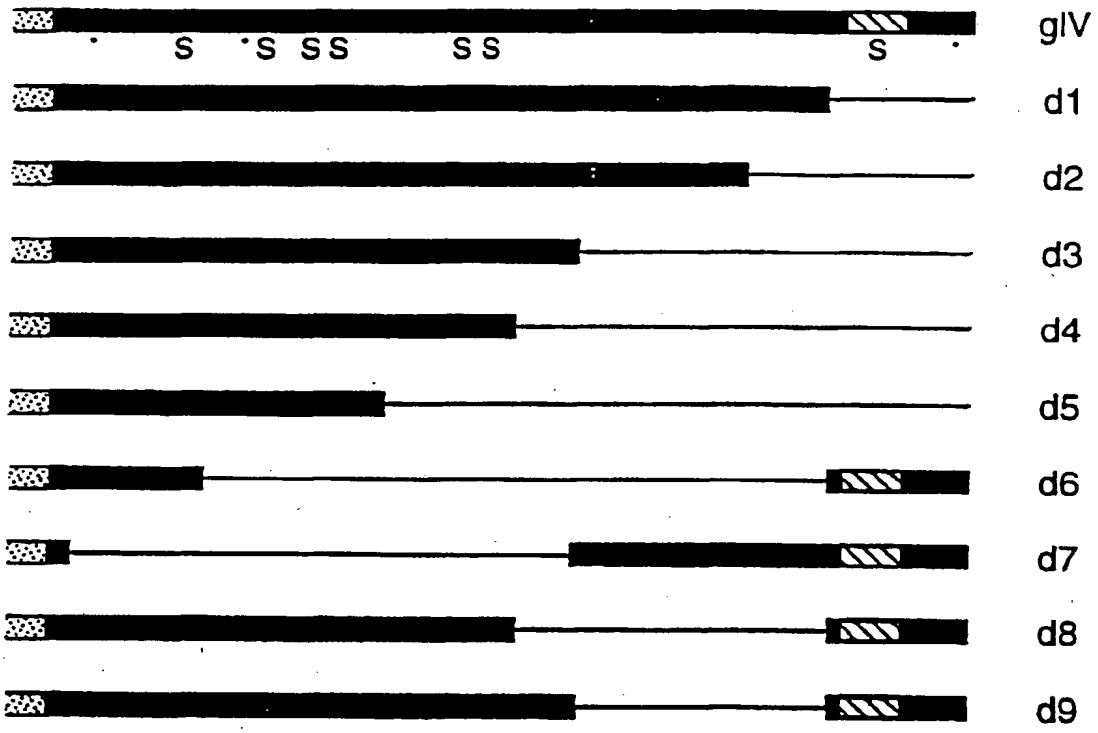

FIG. 15

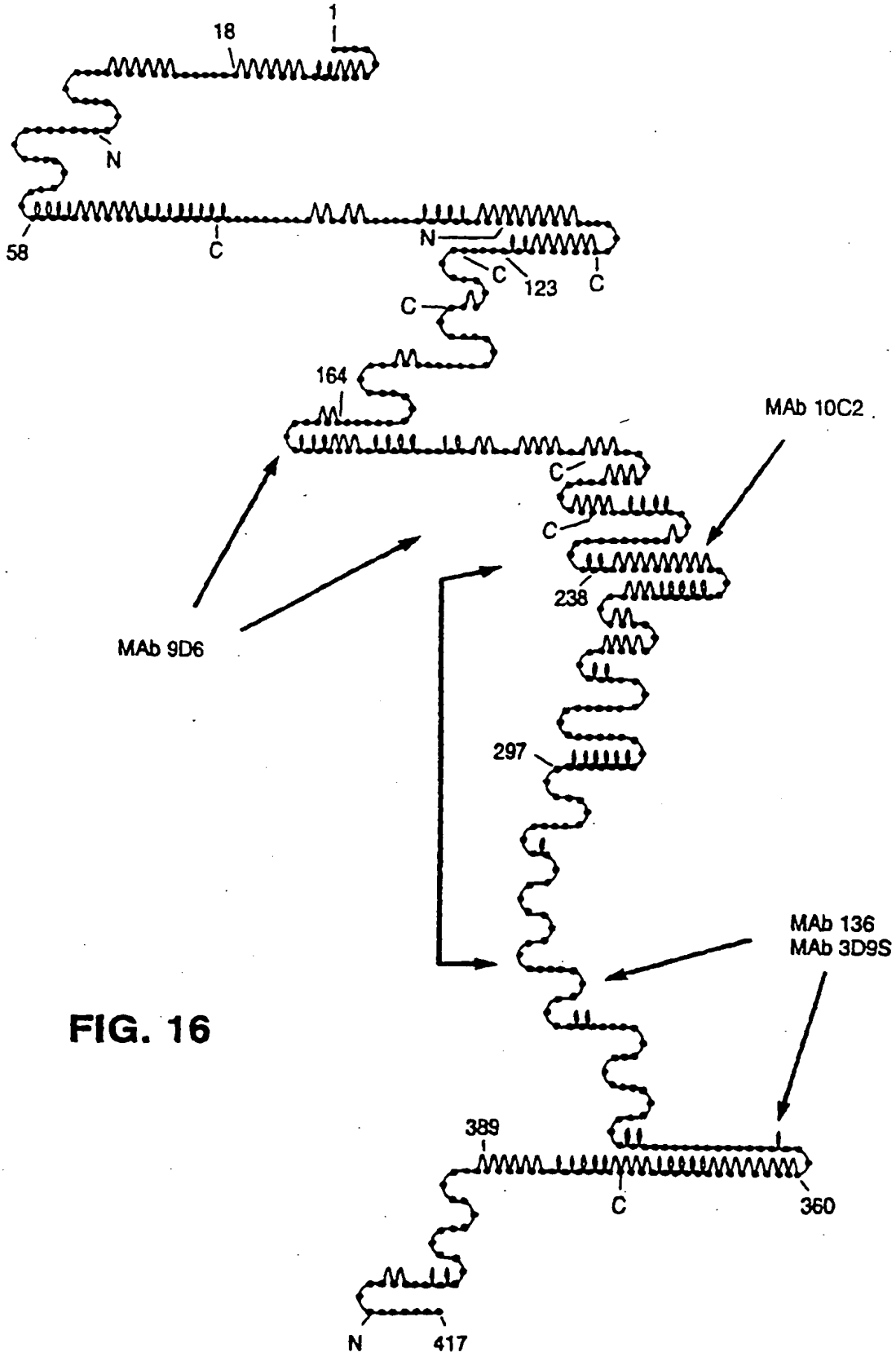

FIG. 16

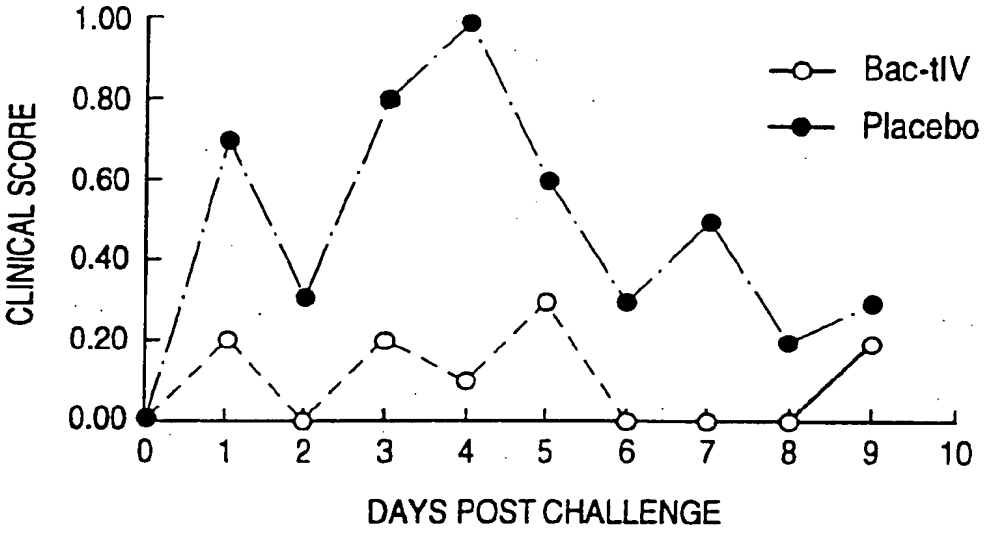

FIG. 17 A

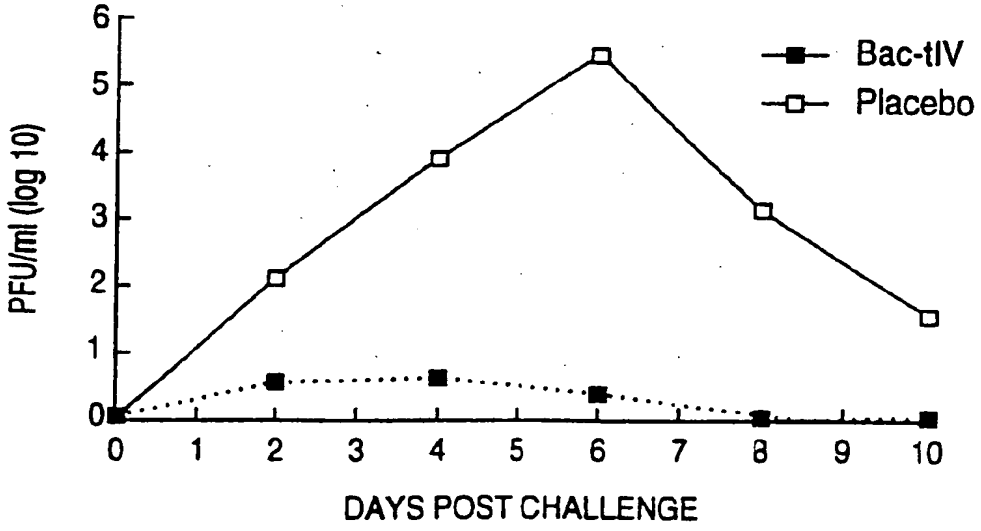

FIG. 17 B

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 888 777 A3

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02.06.1999 Bulletin 1999/22

(43) Date of publication A2:
07.01.1999 Bulletin 1999/01

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(22) Date of filing: **11.12.1992**

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(54) Recombinant bovine herpesvirus type 1 polyptpetides and vaccines

(57) Recombinant subunit vaccines against bovine herpesvirus type 1 (BHV-1) are provided, as well as methods of vaccination and methods of recombinantly producing the subunit antigens or nucleotide sequences employed in the vaccines. Preferably, the subunit is a truncated BHV-1 gIV antigen.

EP 0 888 777 A3

European Patent Office

PARTIAL EUROPEAN SEARCH REPORT

which under Rule 45 of the European Patent Convention shall be considered, for the purposes of subsequent proceedings, as the European search report

Application number

EP 98 10 8774.5

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	Vaccine, Volume 8, August 1990, S. van Drunen Littel-van den Hurk et al, "Epitope specificity of the protective immune response induced by individual bovine herpesvirus-1 glycoproteins" * page 358 - page 368 see fig. 8, Discussion *	28-30	A61K 39/265 C07K 14/03 C12N 15/38
Y	--	1-22, 33-35	
Y	Journal of Virology, Volume 64, No 10, 1990, Suresh K. Tikoo et al, "Molekular Cloning, Sequencing, and Expression of Functional Bovine Herpesvirus 1 Glycoprotein gIV in Transfected Bovine Cells" * page 5132 - page 5142 see page 5134, left column figs 1 and 2, Discussion *	1-7,9, 11-22, 33-35	
	--		

TECHNICAL FIELDS SEARCHED (Int. Cl.4)

A61K
C07K

INCOMPLETE SEARCH

The Search Division considers that the present European patent application does not comply with the provisions of the European Patent Convention to such an extent that it is not possible to carry out a meaningful search into the state of the art on the basis of some of the claims.

Claims searched completely:

Claims searched incompletely:

Claims not searched:

Reason for the limitation of the search:

Remark: Although claims 23-27 and 32 are directed to a method of treatment of (diagnostic method practised on) the human /animal body (Art. 52(4) EPC) the search has been carried out and based on the alleged effects of the compound/composition.

Place of search	Date of completion of the search	Examiner
STOCKHOLM	17 February 1999	CARL-OLOF GUSTAFSSON

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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European Patent Office

PARTIAL EUROPEAN SEARCH REPORT

Application number
EP 98 10 8774.5

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevan to claim	
Y	Journal of Virology, Volume 65, No 1, 1991, S. van Drunen Littel-van den Hurk et al,, "Expression of Bovine Herpesvirus 1 Glycoprotein gIV by Recombinant Baculovirus and Analysis of Its Immunogenic Properties" * page 263 - page 271 see pages 269-270 *	9,10, 14-17	
X	J Immunol, Volume 145, No 2, July 1990, Leary T P et al, "Recombinant herpesviral proteins produced by cell-free translation provide a novel approach for the mapping of T lymphocyte epiopes" page 718 - page 723 *	31	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
Y		1-9, 11-22, 30,31, 33-34	
P	Immunology, Volume 76, No 3, July 1992, Leary T P et al, "Constitutively expressing cell lines that secrete a truncated bovine herpes virus-1 glycoprotein (gpI) stimulate T-lymphocyte responsiveness" page 367 - page 372 *	8	
A	J Immunol, Volume 145, No 3, August 1990, Palmer L D et al, "Bovine natural killer- like cell responses against cell lines expressing recombinant bovine herpesvirus type 1 glycoproteins" page 1009 - page 1014 *	1	

EPO Form 1505.3 06.78

European Patent Office

PARTIAL EUROPEAN SEARCH REPORT

Application number
EP 98 10 8774.5

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevan to claim	
P,X	US 5151267 A (LORNE BABIUK ET AL), 29 September 1992 (29.09.92) * see claims, column 7, line 1 - column 12 *	1-7,9, 11-22, 30,31, 33-35	
	-----		TECHNICAL FIELDS SEARCHED (Int. Cl.5)

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 98 10 8774.5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on 02/02/99
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5151267 A	29/09/92	CA 1338069 A	20/02/96
		US 5585264 A	17/12/96
		US 5858989 A	12/01/99

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82